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# Characterization Well R-32 Completion Report



Los Alamos NM 87545

Produced by the Groundwater Protection Program, Risk Reduction & Environmental Stewardship Division

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## List of Acronyms and Abbreviations

|       |  |
|-------|--|
| AITH  | Array Induction Tool, Version H                  |
| ASTM  | American Society for Testing and Materials       |
| bgs   | below ground surface                             |
| CMR™  | Combinable Magnetic Resonance                    |
| CNTG™ | Compensated Neutron Tool, Model G                |
| DR    | dual rotary                                      |
| ECS™  | Elemental Capture Sonde                          |
| EES   | Earth and Environmental Sciences                 |
| GEL   | General Engineering Laboratories                 |
| GPS   | global positioning system                        |
| GR    | gamma radiation                                  |
| hp    | horse power                                      |
| HSA   | hollow-stem auger                                |
| ICPES | inductively coupled plasma emission spectroscopy |
| ICPMS | inductively coupled plasma mass spectrometry     |
| ID    | inner diameter                                   |
| LANL  | Los Alamos National Laboratory                   |
| MDA   | material disposal area                           |

|        |  |
|--------|--|
| NGS    | Natural Gamma Spectroscopy                   |
| NMED   | New Mexico Environment Department            |
| NTU    | nephelometric turbidity unit                 |
| OD     | outer diameter                               |
| psi    | pounds per square inch                       |
| RC     | reverse circulation                          |
| RRES   | Risk Reduction and Environmental Stewardship |
| SAP    | sampling and analysis plan                   |
| TA     | technical area                               |
| TD     | total depth                                  |
| TLD™   | Triple detector LithoDensity                 |
| UDR    | universal drill rig                          |
| UR-DTH | under-reaming down-the-hole                  |
| VOC    | volatile organic compound                    |
| WCSF   | waste characterization strategy form         |
| WGII   | Washington Group International, Inc.         |
| XRD    | x-ray diffraction                            |
| XRF    | x-ray fluorescence                           |

### Metric to US Customary Unit Conversions

| Multiply SI (Metric) Unit                      | by         | To Obtain US Customary Unit                |
|--|------------|--|
| kilometers (km)                                | 0.622      | miles (mi)                                 |
| kilometers (km)                                | 3281       | feet (ft)                                  |
| meters (m)                                     | 3.281      | feet (ft)                                  |
| meters (m)                                     | 39.37      | inches (in.)                               |
| centimeters (cm)                               | 0.03281    | feet (ft)                                  |
| centimeters (cm)                               | 0.394      | inches (in.)                               |
| millimeters (mm)                               | 0.0394     | inches (in.)                               |
| micrometers or microns ( $\mu\text{m}$ )       | 0.0000394  | inches (in.)                               |
| square kilometers ( $\text{km}^2$ )            | 0.3861     | square miles ( $\text{mi}^2$ )             |
| hectares (ha)                                  | 2.5        | acres                                      |
| square meters ( $\text{m}^2$ )                 | 10.764     | square feet ( $\text{ft}^2$ )              |
| cubic meters ( $\text{m}^3$ )                  | 35.31      | cubic feet ( $\text{ft}^3$ )               |
| kilograms (kg)                                 | 2.2046     | pounds (lb)                                |
| grams (g)                                      | 0.0353     | ounces (oz)                                |
| grams per cubic centimeter ( $\text{g/cm}^3$ ) | 62.422     | pounds per cubic foot ( $\text{lb/ft}^3$ ) |
| milligrams per kilogram ( $\text{mg/kg}$ )     | 1          | parts per million (ppm)                    |
| micrograms per gram ( $\mu\text{g/g}$ )        | 1          | parts per million (ppm)                    |
| liters (L)                                     | 0.26       | gallons (gal.)                             |
| milligrams per liter ( $\text{mg/L}$ )         | 1          | parts per million (ppm)                    |
| degrees Celsius ( $^{\circ}\text{C}$ )         | $9/5 + 32$ | degrees Fahrenheit ( $^{\circ}\text{F}$ )  |

## CHARACTERIZATION WELL R-32 COMPLETION REPORT

### ABSTRACT

Characterization well R-32 was installed as part of Los Alamos National Laboratory's hydrogeologic work plan under the direction of the Laboratory's Risk Reduction and Environmental Stewardship Division. Washington Group International, Inc., was subcontracted by Los Alamos National Laboratory to carry out drilling activities. The well is located in Pajarito Canyon, within Technical Area (TA)-36 on the north side of Pajarito Road and southwest of Material Disposal Area G in TA-54. The primary purpose of this well is to provide hydrogeologic and water-quality data for regional groundwater near potential contaminant release sites at TA-54.

Hydrologic, geologic, geochemical, and geophysical information obtained during well completion and subsequent sampling at well R-32 will provide data for the Laboratory hydrologic and geologic conceptual models and contribute to implementing a Laboratory-wide groundwater monitoring system. Monitoring this network of wells supports the Laboratory's Groundwater Protection Management Program plan and will help characterize the regional aquifer in this area.

Borehole R-32 was drilled to a total depth of 1008 ft using both fluid-assisted reverse-circulation air-rotary drilling and conventional mud-rotary drilling methods. Well installation included placement of three screens within the regional aquifer. The well was completed on August 12, 2002, and the Westbay™ multiport system was installed on November 16, 2002.

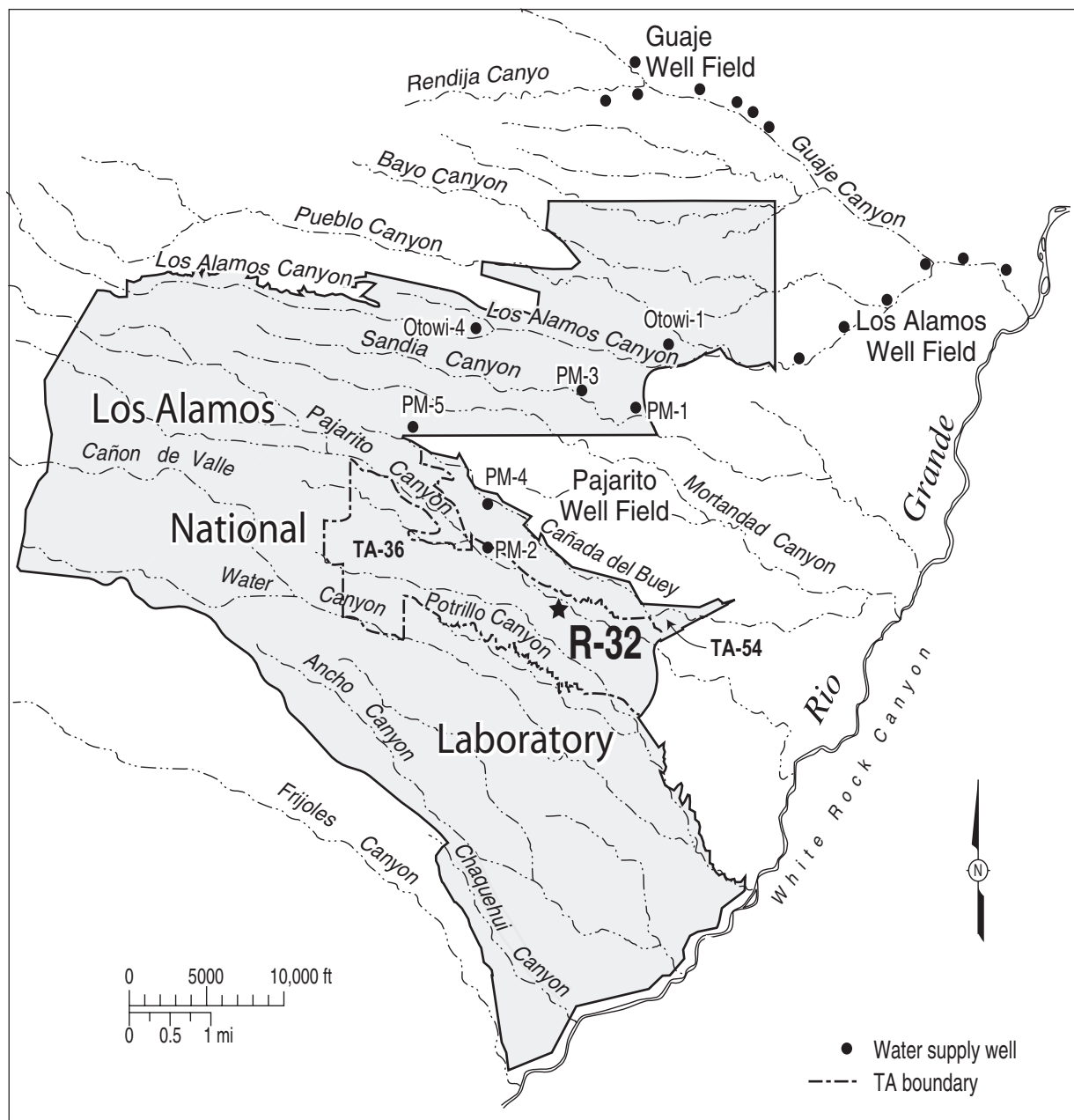
Geologic strata encountered during drilling operations included the following in descending order: alluvial sediments; the lower Tshirege Member of the Bandelier Tuff; Cerro Toledo sediments; ash flows of the Otowi Member of the Bandelier Tuff; the Guaje Pumice Bed of the Bandelier Tuff; lavas, scoria, and interflow units of the Cerros del Rio volcanic field; and suspected fanglomerates of the Puye Formation.

Perched groundwater was encountered in alluvium at a depth of 22 ft. No other perched zones were identified in deeper geologic units. The regional zone of saturation was first penetrated in Cerros del Rio basalt. A composite depth for the regional water table in the Cerros del Rio basalt, measured after well construction and before Westbay™ installation, was 783.4 ft below ground surface.

Following well development activities, three groundwater samples were taken, one from each screened interval at depths of 871, 933, and 977 ft, primarily to determine if potential contaminants were present in the regional aquifer. Major potential contaminants of concern at well R-32 include mobile solutes such as nitrate, perchlorate, uranium, and tritium. Based on analytical results for the samples, contamination from Laboratory discharges does not appear to be present in the regional aquifer at this well site.

## 1.0 INTRODUCTION

This well completion report for characterization well R-32 summarizes the preparation, drilling, well construction, well development, and site completion activities conducted from July 3 to July 9, 2002. Well R-32 is located in Pajarito Canyon within Technical Area (TA)-36 of Los Alamos National Laboratory (LANL or the Laboratory) on the north side of Pajarito Road and southwest of Material Disposal Area (MDA) G, which is located in TA-54 (Figure 1.0-1). The well was installed as part of the "Hydrogeologic Workplan," in support of the Laboratory's "Groundwater Protection Management Program Plan" (LANL 1998, 59599; LANL 1996, 70215).



**Figure 1.0-1. Location map, characterization well R-32**

The project was funded by the Nuclear Weapons Infrastructure, Facilities, and Construction Program, and the well was installed by the Laboratory's Risk Reduction and Environmental Stewardship (RRES) Division. Washington Group International, Inc. (WGII), under contract to the Laboratory, was responsible for executing drilling activities.

The primary function of this well is to investigate the nature and extent of impacts to regional groundwater that resulted from Laboratory activities in the Pajarito Canyon watershed. Water-quality, geochemical, hydrologic, and geologic information gathered during well completion will augment knowledge of regional subsurface characteristics and the distribution of possible contaminants downgradient of Laboratory activities. Data will support on-going performance assessments at MDA G, provide a basis for groundwater monitoring at TA-54, and be used to update sitewide hydrologic and geologic conceptual models for the Laboratory.

This well completion report describes operational activities associated with the drilling, sampling, and completion of characterization well R-32. Information presented in this report was compiled from field reports and activity summaries generated by Laboratory and subcontractor personnel. Geophysical data provided by Schlumberger, Inc. (Schlumberger), and geodetic survey results are included as well. Detailed analysis and interpretation of geologic, geochemical, geophysical, and hydrologic data will be included in separate technical documents to be prepared by the Laboratory.

## **2.0 PRELIMINARY ACTIVITIES**

Preliminary activities at R-32 included administrative functions and site preparation. Appendix A compares the activities planned in the "Sampling and Analysis Plan (SAP) for the Drilling of Characterization Wells R-16, R-20, R-21, R-23, and R-32 in the Vicinity of TA-54" with work performed (LANL 2002, 73390).

WGII received contractual authorization to start administrative preparation tasks for well R-32 on June 6, 2002. As part of this preparation, WGII developed a modification to existing site-specific health and safety plan No. 271 to include well R-32. WGII also prepared the R-32 waste characterization strategy form (WCSF). The Laboratory prepared a sampling and analysis plan (SAP) to guide field personnel in the execution of field activities. The host facility, Facility Management Unit 80, signed a Facility Tenant Agreement to provide area access and security control for R-32 activities.

A readiness review meeting was held on July 1, 2002, to discuss all administrative agreements, documents, permits, and plans pertaining to the project. The Groundwater Investigations Focus Area project leader signed the readiness review checklist on July 1, 2002, giving authorization to begin work.

K. R. Swerdfeger Construction, Inc., was subcontracted by WGII to prepare the site for drilling, including clearing the site, grading and compacting for the drill pad area, and constructing a lined cuttings-containment area. Site preparation was completed between July 3 and 9, 2002.

The R-32 site initially was cleared of small trees and vegetation. The drill pad was constructed by leveling a 100-ft by 150-ft area and then grading and compacting base-course gravel across the site to complete the drill pad. To store drilling fluids and cuttings, a containment area approximately 80 ft long by 25 ft wide by 12-ft deep was excavated along the boundary of the north pad. A berm, roughly 3 ft high, was constructed around the cuttings-containment area, and the entire excavation area was lined with a 6-mil polyethylene liner. A secondary containment area was bermed and lined with 6-mil polyethylene to accommodate two 20,000-gal.-tank trailers that were used to store drilling fluids. Silt fences were constructed as needed around the site, and safety barriers and signs were installed around the cuttings-

containment area and other appropriate areas. Office and supply trailers, generators, and safety lighting equipment were moved to the site when drilling equipment was mobilized.

### 3.0 SUMMARY OF DRILLING ACTIVITIES

Drilling activities at the R-32 site were completed in two phases by Dynatec Drilling Company, Inc. (Dynatec), during July and August 2002. Phase I drilling and core sampling was performed using a Foremost™ universal drill rig (UDR)-1000 equipped with a wire-line core-retrieval system and a 5-ft long core barrel that was used to collect 2.5-in.-diameter core samples. Phase II drilling was performed using a Foremost™ dual-rotary (DR)-24 drill rig, equipped with reverse-circulation (RC) drilling rods, tricone bits, down-the-hole (DTH) hammer bits, and support equipment. Drill-fluid mixing and circulation equipment included a mixing tank and pump assembly, a generator to power the mixing unit, a shaker unit to remove solids from the discharged drilling fluids, and an auxiliary pump. Equipment and fabrication support for drilling activities was provided by RRES Division's Field Support Facility.

The borehole was drilled using both fluid-assisted RC air-rotary and conventional mud-rotary drilling techniques with open-hole or casing-advance methods, as determined by changing geologic and drilling conditions. Additives were mixed with municipal water to improve borehole stability, minimize fluid loss, and facilitate cuttings removal from the borehole. Air-rotary drilling was assisted with a foam mixture consisting of municipal water mixed with soda ash, QUICK-GEL® (bentonite), LIQUI-TROL® (polymer), and QUICK-FOAM® (surfactant). The fluid mixture used to assist mud-rotary drilling at R-32 typically consisted of municipal water mixed with QUICK-GEL® and LIQUI-TROL®. During drilling operations, lost circulation material (Magma-Fiber® and N-seal®) was used to help maintain or regain circulation within the borehole. Appendix B contains a list of drill additives used at well R-32. Table 3.0-1 summarizes the quantities of additives and fluids used to drill this well.

**Table 3.0-1**  
**Fluid Additives Used, Characterization Well R-32**

| Additive                              | Amount | Unit of Measure |
|---------------------------------------|--------|-----------------|
| <b>Interval Drilled (0–792 ft)</b>    |        |                 |
| Water                                 | 53,000 | gal.            |
| QUICK-GEL®                            | 20,000 | lb              |
| LIQUI-TROL®                           | 175    | gal.            |
| QUICK-FOAM®                           | 550    | gal.            |
| Soda ash                              | 400    | lb              |
| <b>Interval Drilled (792–1008 ft)</b> |        |                 |
| Water                                 | 45,000 | gal.            |
| QUICK-GEL®                            | 25,000 | lb              |
| EZ-Mud®                               | 25.5   | gal.            |
| LIQUI-TROL®                           | 5      | gal.            |
| Pac-L®                                | 50     | lb              |
| N-seal®                               | 800    | lb              |
| Magma Fiber®                          | 800    | lb              |

The objective of Phase I drilling was to collect continuous rock core samples to characterize geologic units encountered and to determine moisture, anion, stable isotope, radionuclide, metals, and tritium distributions in the upper section of the borehole. Planned total depth (TD) for Phase I drilling was 344 ft below ground surface (bgs) or approximately 50 ft into the Cerros del Rio basalt. Groundwater samples were to be collected during Phase I if significant perched water was encountered in bedrock units. Phase II objectives were to collect cuttings of geologic formations encountered, collect water samples from perched and regional groundwater zones, and provide a borehole for geophysical measurements and the installation of a multiple-screen well in the regional aquifer. The planned depth for Phase II drilling was approximately 1356 ft bgs.

Figure 3.0-1 summarizes well data and depicts groundwater and geologic conditions encountered in well R-32. Figure 3.0-2 shows the drilling chronology and other on-site activities. Sections 3.1 and 3.2 discuss Phase I and Phase II drilling activities, respectively.

### **3.1 Phase I Drilling**

On July 11, 2002, Dynatec mobilized the UDR-1000 drill rig and support equipment at the R-32 site, performed routine maintenance activities the following day, and began coring on July 13, 2002. To stabilize alluvial sediments, Dynatec installed a 5-in.-diameter steel surface casing from the surface to 16 ft bgs. Coring proceeded to 66 ft bgs with repeated caving of the borehole wall and persistently poor core recovery. This borehole instability can be attributed to the presence of alluvial groundwater at 22 ft bgs and Dynatec's inability to adequately seal off this zone from deeper drilling. Thus, the Laboratory decided to plug and abandon the first borehole on July 14, 2002. Dynatec relocated the UDR-1000 to a new site 10 ft to the east and cored from the surface to 50.5 ft bgs, where a 6.125-in. temporary surface casing was landed in the Tshirege Member of the Bandelier Tuff at 59.1 ft bgs on July 15, 2002. Coring then resumed through Otowi Member ash flows of the Bandelier Tuff, through the underlying Guaje Pumice Bed, and 32 ft into Cerros del Rio basalt to a TD of 318 ft bgs. Coring was terminated at this depth because large voids were encountered in the basalt that threatened to compromise the alignment of the borehole and adversely impact further drilling operations. Coring objectives generally had been met because samples had been collected from the Bandelier Tuff and from the top of the Cerros del Rio basalt. Phase I drilling operations concluded on July 18, 2002, and the UDR-1000 drill rig was demobilized.

### **3.2 Phase II Drilling**

On July 18, 2002, Dynatec mobilized the Foremost™ DR-24 drill rig and support equipment to the R-32 drill site. The DR-24 was positioned over the previously cored hole, and the 6.125-in. temporary surface casing was removed from the borehole. On July 19, 2002, Dynatec reamed and landed an 18-in. surface casing from the surface to 57 ft bgs using a 16-in. tricone bit. The leading edge of the 18-in. casing was modified with a hardened cutting surface to advance further into the borehole behind the 16-in. tricone bit. While the drill stem was being tripped out, the drill bit encountered an obstruction in the 18-in. casing. After several attempts to free the bit, Dynatec removed the drill string and surface casing. It was discovered that the formation materials had split open the surface casing. This borehole was plugged and abandoned on July 20, 2002.

Location: In Pajarito Canyon, south of TA-54, along the north side of Pajarito Rd.

Survey coordinates (brass marker in NW corner of R-32 cement pad):  
x: 1640798 E y: 1757730 N (NAD 83)  
z: 6637.6 ft asl (NGVD 29)

Drilling: air rotary core w/ wireline retrieval, conventional mud drilling.

R-32 Start date: 07/13/02.

R-32 End date: 08/7/02.

Borehole R-32 drilled to 1008 ft. bgs. (T.D.).

Data collection:

Hydrologic properties: Field hydraulic test:

Constant Rate Injection Test on screen #1 and screen #3

Cores/cuttings submitted for geochemical and contaminant characterization: (13)

Groundwater samples submitted for geochem and contaminant characterization: (3)

Geologic properties: (7)

Mineralogy, petrography, and chemistry.

Borehole logs from R-32:

Lithologic: 0-915.5 ft.

Caliper (LANL): 0-1008 ft.

Video (LANL tool): 0-720 ft.

Natural gamma + Induction (LANL tool): 0-808 ft. and 0-1008 ft.

Schlumberger Logs: 0-54.5 ft. (cased), 54.5-808 ft. (open hole): Epithermal Neutron, Litho density, Induction, Combinable Magnetic Resonance, Elemental Capture, Spectral Gamma.

Contaminants Detected in R-32 Water Samples: none

Well construction:

Drilling Completed: 08/07/02

Contract Geophysics: 07/31/02

Well Constructed : 08/09/02 - 08/12/02

Well Developed : 8/18/02 - 11/10/02

Westbay Installed : 11/11/02 - 11/17/02

Casing: 4.5-in I.D. stainless steel with external couplings.

Number of Screens: 3

4.5-in I.D. pipe based, s.s. wire-wrapped with 0.010-in slots.

Screen (perforated pipe interval):

Screen #1 - 867.5 - 875.2 ft. bgs.

Screen #2 - 931.8 - 934.9 ft. bgs.

Screen #3 - 972.9 - 980.6 ft. bgs.

Well development consisted of wire brushing, bailing, chemical treatments, surging, and pumping.

Static water level measured on November 11, 2002, at 783.4 ft in completed and developed well.

Groundwater samples collected from packed off screen intervals after well development.

Geologic contacts for R-32 were determined by examination of cuttings and interpretation of geophysical logs. Contacts may be refined by petrographic, geochemical, or mineralogic analysis of geologic samples.

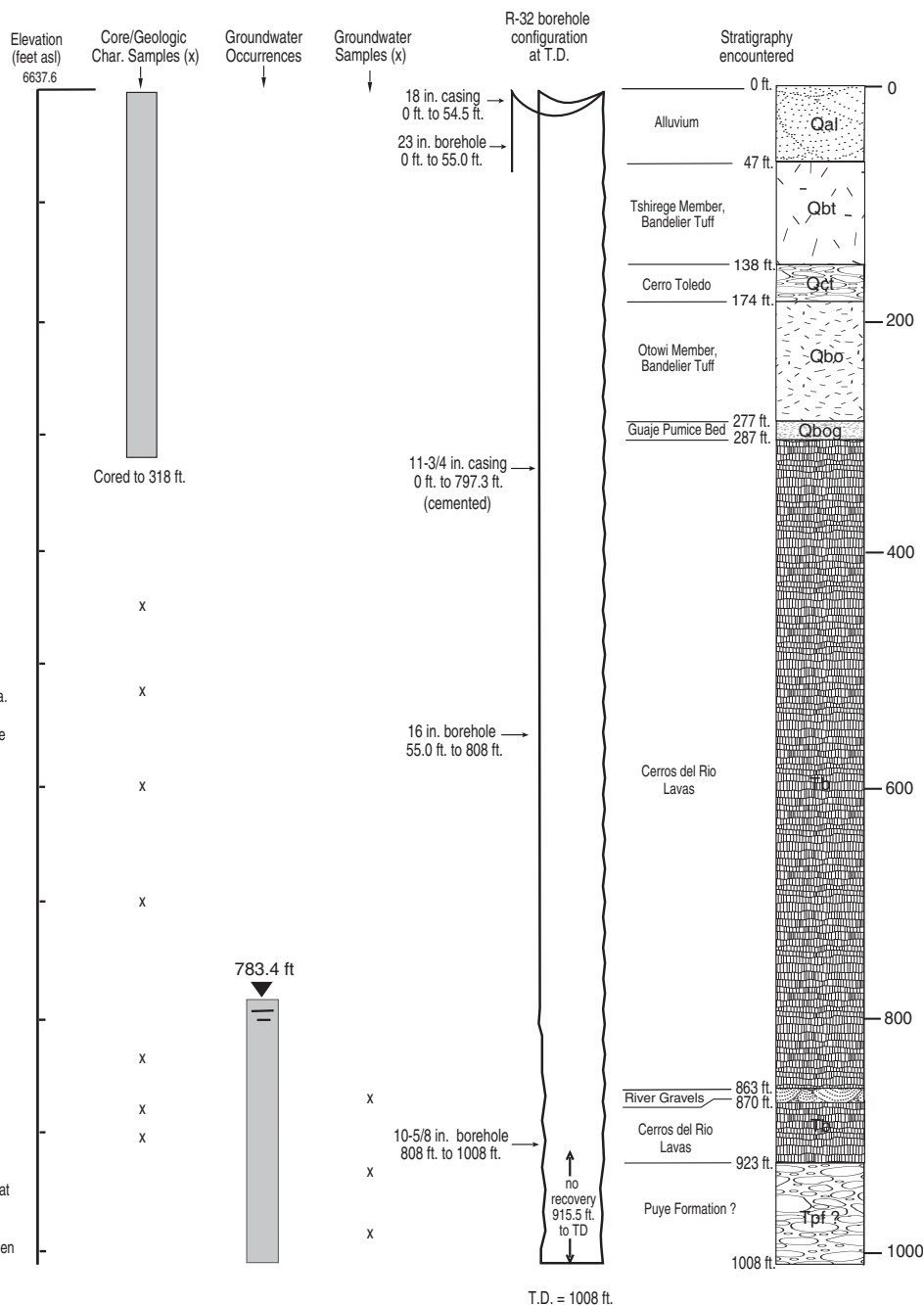


Figure 3.0-1. Well data summary sheet, characterization well R-32

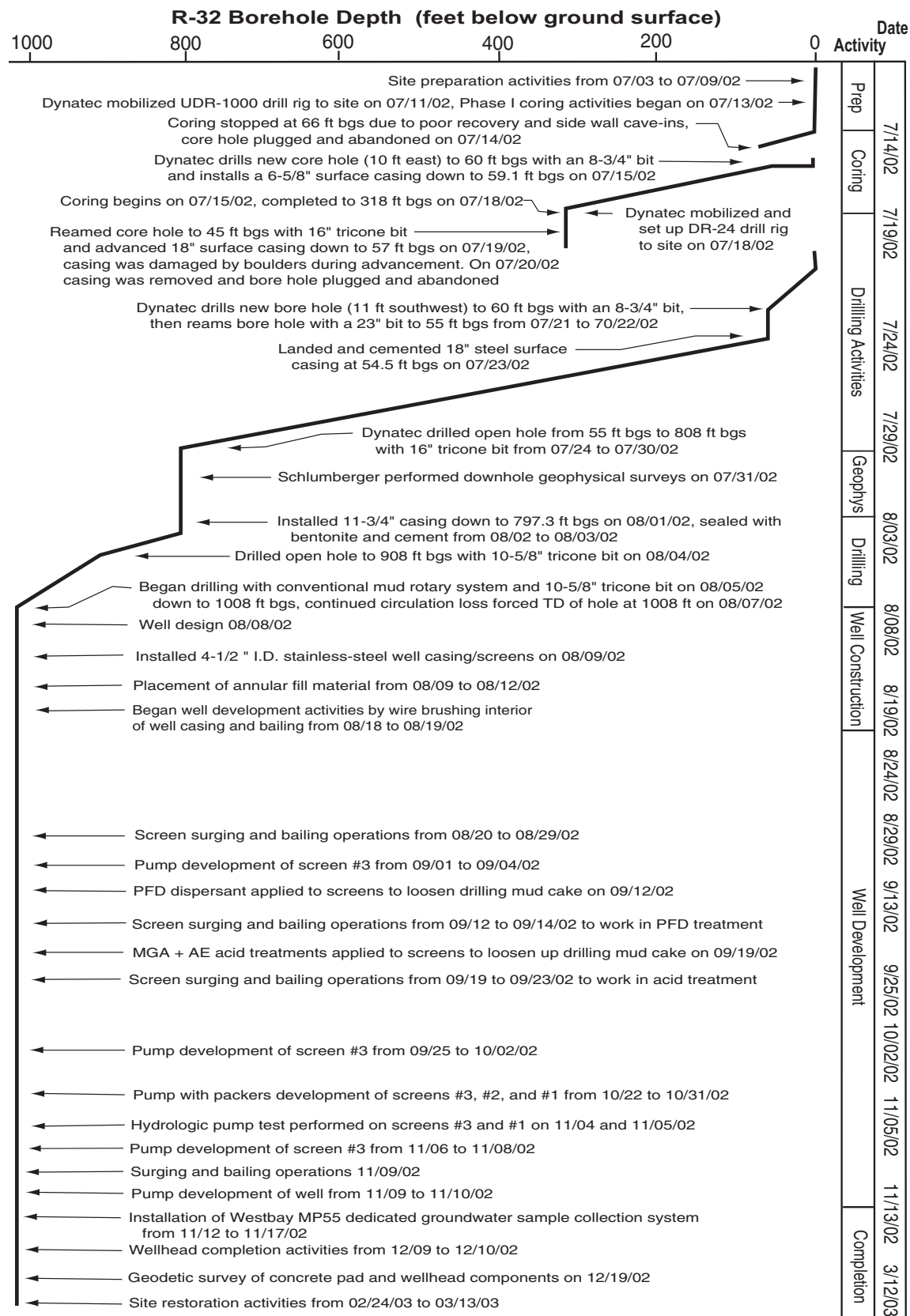


Figure 3.0-2. Operations chronology diagram, characterization well R-32

On July 21, 2002, Dynatec moved the DR-24 drill rig to a new location approximately 11 ft southwest of the abandoned borehole. Dynatec began drilling a new borehole with an 8.75-in. tricone bit from the surface to 60 ft bgs and then with a 23-in. quadcone reamer drill bit from the surface to 55 ft bgs. An 18-in. surface casing then was installed and landed at 54.5 ft bgs and cemented in place. On July 24, 2002, Dynatec began open-hole drilling with a 16-in. tricone drill bit from 55 ft bgs using fluid-assisted air-rotary drilling methods. Drilling continued for the next several days and reached 808 ft bgs on July 30, 2002. On August 1, 2002, following geophysical logging, the water level was measured at 726.9 ft bgs. While drilling in the above interval, Dynatec added lost circulation materials (N-Seal<sup>®</sup> and Magma Fiber<sup>®</sup>) to improve circulation.

Open-borehole geophysics surveys were conducted on July 31, 2002, while 11.75-in. thin-walled steel conductor casing was mobilized to the site. After the borehole stabilized, the water level was measured at 726.9 ft bgs.

After the geophysical surveys were complete, the 11.75-in. conductor casing was installed and landed at 797.3 ft bgs. The annulus was grouted from the bottom of the casing to 644.5 ft bgs with cement, backfilled from 644.5 to 70 ft bgs with Hole-Plug<sup>®</sup> bentonite chips, and filled with cement grout from 70 ft to the surface. Open-hole drilling continued on August 4, 2002, from 808 to 908 ft bgs using a 10.625-in. tricone drill bit. On August 5, 2002, Dynatec switched to the conventional mud-rotary system. The borehole then was advanced open-hole to 1008 ft bgs, where drilling at R-32 was terminated because drilling-mud circulation could not be re-established. On August 7, 2002, the borehole was reamed to 1008 ft bgs TD to prepare for borehole geophysical surveys and well installation.

#### **4.0 SAMPLING AND ANALYSIS OF DRILL CORE AND GROUNDWATER**

Core samples were collected from R-32 and analyzed for anions using ion chromatography and radionuclides using counting techniques. Thirteen core samples were collected from the vadose zone during drilling from 19.0 to 302.0 ft bgs. Approximately 500 to 1000 g of core or cuttings samples were placed in appropriate sample jars in protective plastic bags before they were analyzed by Earth and Environmental Sciences (EES)-6 and General Engineering Laboratories (GEL). The samples were used also to prepare a lithologic log (Appendix C).

Alluvial groundwater was encountered at 22 ft bgs. No samples were collected and analyzed for inorganic and organic chemicals and radionuclides. No perched intermediate groundwater was encountered at well R-32 during fluid-assisted drilling. A composite static water level was measured at 783.4 ft in the completed, developed well on November 11, 2002. Three regional aquifer water samples were collected from the developed well and analyzed for a limited suite of constituents. These samples were collected from screen 1 (867.5–875.2 ft), screen 2 (931.8–934.9 ft), and screen 3 (972.9–980.6 ft). The samples were collected at depths of 871, 933, and 977 ft primarily to determine if potential contaminants were present in the regional aquifer. Major potential contaminants of concern at R-32 include mobile solutes such as nitrate, perchlorate, uranium, and tritium.

#### **Geochemistry of Sampled Waters**

Groundwater samples analyzed for inorganic and organic chemicals, tritium, and other radionuclides were collected by using a submersible pump and packers. Temperature, turbidity, pH, alkalinity, and specific conductance were determined on the site. Both filtered (metal, trace-element, and major cation and anion) and nonfiltered (radionuclide, organic-compound, and stable-isotope) samples were collected for chemical and radiochemical analyses. Aliquots of the samples were filtered through a 0.45- $\mu$ m Gelman filter. Samples were acidified with analytical-grade nitric acid to a pH of 2.0 or less for metal and major ion analyses. All groundwater samples collected in the field were stored at 4°C until they were analyzed.

Alkalinity was determined in the laboratory using standard titration techniques, which may approximate field conditions because of sample degassing, including carbon dioxide gas.

Groundwater samples were analyzed by EES-6 using techniques specified in the US Environmental Protection Agency SW-846 manual (LANL 2000, 71233). Ion chromatography was the analytical method used for bromide, chloride, fluoride, nitrate, nitrite, oxalate, perchlorate, phosphate, and sulfate. Mercury was analyzed by cold vapor atomic absorption. Inductively coupled (argon) plasma emission spectroscopy (ICPES) was the analytical method used for calcium, magnesium, potassium, silica, and sodium. Aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, selenium, silver, thallium, vanadium, uranium, and zinc were analyzed by inductively coupled (argon) plasma mass spectrometry (ICPMS).

Radionuclide activity in groundwater was determined by electrolytic enrichment for tritium; alpha spectrometry for plutonium and uranium isotopes; gas proportional counting for strontium-90; liquid scintillation for technetium-99; and gamma spectrometry for cesium-137, americium-241, and other gamma-emitting isotopes. Volatile organic compounds (VOCs) were analyzed by gas chromatography-mass spectrometry. Contract laboratories performing this work were GEL (radionuclides and VOCs) and the University of Miami (low-level tritium). Stable isotopes of oxygen (oxygen-18 and oxygen-16,  $\delta^{18}\text{O}$ ) and hydrogen (hydrogen and deuterium,  $\delta\text{D}$ ) were analyzed by Geochron Laboratories (Cambridge, Massachusetts) using isotope ratio mass spectrometry.

The precision limits (analytical error) for major ions and trace elements generally were less than  $\pm 10\%$  using ICPES and ICPMS.

Results of screening analyses for the three groundwater samples collected from the Cerros del Rio basalt in R-32 are provided in Tables 4.1-1 and 4.1-2. Detected VOCs are also provided in Table 4.1-2. Based on analytical results for the samples, contamination from Laboratory discharges does not appear to be present in the regional aquifer at this well site.

**Table 4.1-1**  
**Hydrochemistry of Regional Aquifer Samples, Characterization Well R-32**

| Parameter and Analyte                            | Cerros del Rio Basalt Screen 1 (871 ft bgs) 10/31/02 | Cerros del Rio Basalt Screen 2 (933 ft bgs) 10/30/03 | Cerros del Rio Basalt Screen 2 (977 ft bgs) 10/28/03 |
|--|--|--|--|
| <b>Parameter</b>                                 |  |  |  |
| pH   | 6.88   | 6.75   | 6.75   |
| Temperature (°C)                                 | 24.4   | 23.6   | 22.4   |
| Specific conductance ( $\mu\text{S}/\text{cm}$ ) | 251  | 143  | 97   |
| Turbidity (NTU)                                  | 3.73   | 3.34   | 1.91   |
| <b>Analyte</b>                                   |  |  |  |
| Alkalinity (mg $\text{CaCO}_3/\text{L}$ )        | 86   | 53   | 61   |
| Al (mg/L)  | 0.006  | 0.011  | 0.009  |
| Sb (mg/L)  | [0.0001], U  | 0.0002   | 0.0003   |
| As (mg/L)  | 0.0010   | 0.0012   | 0.0010   |

Table 4.1-1 (continued)

| Parameter and Analyte                          | Cerro del Rio Basalt Screen 1 (871 ft bgs) 10/31/02 | Cerro del Rio Basalt Screen 2 (933 ft bgs) 10/30/03 | Cerro del Rio Basalt Screen 2 (977 ft bgs) 10/28/03 |
|--|---|---|---|
| Ba (mg/L)                                      | 0.052   | 0.023   | 0.043   |
| Be (mg/L)                                      | [0.001], U  | [0.001], U  | [0.001], U  |
| Br (mg/L)                                      | 0.10  | 0.09  | 0.09  |
| Cd (mg/L)                                      | [0.001], U  | [0.001], U  | [0.001], U  |
| Ca (mg/L)                                      | 19.1  | 9.65  | 11.4  |
| Cl (mg/L)                                      | 7.67  | 2.70  | 3.90  |
| ClO <sub>4</sub> (mg/L)                        | [0.002], U  | [0.002], U  | [0.002], U  |
| Cr (mg/L)                                      | 0.0025  | 0.0019  | 0.0011  |
| Co (mg/L)                                      | 0.0070  | 0.0012  | 0.0035  |
| Cu (mg/L)                                      | 0.0028  | 0.0041  | 0.0048  |
| F (mg/L)                                       | 0.25  | 0.60  | 0.41  |
| Fe (mg/L)                                      | 0.67  | 0.41  | 0.31  |
| Pb (mg/L)                                      | 0.0002  | 0.0004  | 0.0003  |
| Mg (mg/L)                                      | 5.83  | 2.80  | 3.16  |
| Mn (mg/L)                                      | 0.73  | 0.86  | 0.68  |
| Hg (mg/L)                                      | [0.00005], U  | [0.00005], U  | 0.00027   |
| Mo (mg/L)                                      | 0.0047  | 0.0021  | 0.0021  |
| Ni (mg/L)                                      | 0.011   | 0.0048  | 0.0060  |
| NO <sub>3</sub> (mg/L) (as N)                  | 0.02  | 0.58  | 0.05  |
| NO <sub>2</sub> (mg/L) (as N)                  | [0.005], U  | [0.005], U  | [0.005], U  |
| C <sub>2</sub> O <sub>4</sub> (mg/L) (oxalate) | [0.02], U   | [0.02], U   | [0.02], U   |
| PO <sub>4</sub> (mg/L) (as P)                  | 0.23  | 1.53  | 1.31  |
| K (mg/L)                                       | 2.08  | 1.82  | 1.82  |
| Se (mg/L)                                      | [0.001], U  | [0.001], U  | [0.001], U  |
| Ag (mg/L)                                      | [0.001], U  | [0.001], U  | [0.001], U  |
| Na (mg/L)                                      | 20.1  | 12.4  | 13.8  |
| SiO <sub>2</sub> (mg/L)                        | 63.3  | 68.3  | 69.6  |
| Sr (mg/L)                                      | 0.094   | 0.046   | 0.063   |
| SO <sub>4</sub> (mg/L)                         | 11.7  | 4.20  | 3.62  |
| Tl (mg/L)                                      | [0.001], U  | [0.001], U  | [0.001], U  |
| U (mg/L)                                       | 0.0007  | 0.0003  | 0.0004  |
| V (mg/L)                                       | 0.002   | 0.004   | 0.003   |
| Zn (mg/L)                                      | 0.43  | 0.67  | 0.78  |
| TDS (mg/L) (calculated)                        | 238   | 176   | 188   |

Notes: 1. U = not detected.

2. Silica concentrations were calculated from measured silicon (ICPES).

3. NTU = nephelometric turbidity unit.

4. Filtered samples analyzed by EES-6.

**Table 4.1-2**  
**Radiochemistry of Regional Aquifer Samples, Characterization Well R-32**

| <b>Analyte</b>        | <b>Cerros del Rio Basalt<br/>(871 ft bgs)<br/>Screen 1<br/>10/31/02)</b> | <b>Cerros del Rio Basalt<br/>(933 ft bgs)<br/>Screen 2<br/>10/30/02</b> | <b>Cerros del Rio Basalt<br/>(977 ft bgs)<br/>Screen 3<br/>10/28/02</b> |
|-----------------------|--|---|---|
| Tritium (pCi/L)       | [0.39], U  | [-0.03], U  | [0], U  |
| Am-241 (pCi/L)        | [4.73], U  | [7.15], U   | [-1.71], U  |
| Cs-137 (pCi/L)        | [-0.108], U  | [-0.177], U   | [-0.242], U   |
| Gross alpha (pCi/L)   | [-0.118], U  | [-0.29], U  | [-0.214], U   |
| Gross beta (pCi/L)    | [1.55], U  | [0.652], U  | [1.86], U   |
| Pu-238 (pCi/L)        | [0.003], U   | [-0.004], U   | [-0.005], U   |
| Pu-239,240 (pCi/L)    | [-0.005], U  | [-0.031], U   | [-0.003], U   |
| Sr-90 (pCi/L)         | [-0.013], U  | [0.010], U  | [-0.102], U   |
| Tc-99 (pCi/L)         | [1.35], U  | [0.665], U  | [0.854], U  |
| U-234 (pCi/L)         | 0.474  | 0.234   | 0.201   |
| U-235 (pCi/L)         | [0.0154], U  | [0.0239], U   | [0.0195], U   |
| U-238 (pCi/L)         | 0.228  | 0.0998  | 0.121   |
| TOC (mg/L C)          | 10.1   | 10.7  | 5.77  |
| Acetone (µg/L)        | 2020   | 31.0  | 74.9  |
| Benzene (µg/L)        | [1], U   | 1.4   | [1], U  |
| δD (‰)                | -86  | -86   | —   |
| δ <sup>18</sup> O (‰) | -10.9  | -11   | —   |

**Notes:** 1. U = not detected.  
2. Dash = "not analyzed."  
3. ‰ = permil.  
4. TOC = total organic carbon.  
5. Americium-241 was analyzed by gamma spectroscopy.  
6. Nonfiltered samples analyzed by GEL, Geochron Laboratories, and University of Miami.  
7. Standard deviation is 1 sigma.

## 5.0 BOREHOLE GEOPHYSICS

LANL and Schlumberger provided geophysical logging services at R-32. Table 5.0-1 lists borehole and well logging surveys conducted.

**Table 5.0-1**  
**Borehole and Well Logging Surveys Conducted, Characterization Well R-32**

| Surveyor     | Date              | Method                                | Cased Footage | Open-Hole Interval (ft bgs) | Remarks   |
|--------------|-------------------|---------------------------------------|---------------|-----------------------------|---|
| WGII/LANL    | July 18, 2002     | Video                                 | 0–59.1        | 59.1–318                    | Conducted in borehole at completion of Phase I drilling (coring)  |
| WGII/LANL    | July 31, 2002     | Video, natural gamma, and induction   | 0–54.5        | 54.5–808                    | Conducted in borehole prior to installation of 11.75-in. thin-walled conductor casing   |
| Schlumberger | July 31, 2002     | Logging suite <sup>a,b</sup>          | 0–54.5        | 54.5–808                    | Conducted in borehole prior to installation of 11.75-in. thin-walled conductor casing   |
| WGII/LANL    | August 7, 2002    | Natural gamma, induction, and caliper | 0–797.3       | 797.3–1008                  | Conducted prior to well design and installation   |
| WGII/LANL    | November 5, 2002  | Video, natural gamma                  | 0–1002        | NA <sup>c</sup>             | Document and verify condition of well screen intervals and interior of well. Natural gamma tool was run to verify backfill placement. |
| WGII/LANL    | November 8, 2002  | Video                                 | 0–1002        | NA                          | Document and verify condition of well screen intervals and interior of well   |
| WGII/LANL    | November 10, 2002 | Video                                 | 0–1002        | NA                          | Document and verify condition of well screen intervals and interior of well prior to installation of Westbay™ system                  |

<sup>a</sup> Schlumberger's suite of borehole logging surveys included array induction, combinable magnetic resonance, triple lithodensity, elemental capture, natural gamma ray spectroscopy, thermal/epithermal compensated neutron log, and natural gamma.

<sup>b</sup> The combinable magnetic resonance log was run only in the open portion of the borehole.

<sup>c</sup> NA = Not applicable; logs were run inside the well casing.

## 5.1 Laboratory-Supported Geophysical Logging

Natural gamma logs have proven successful in discriminating between geologic units that contain varying concentrations of uranium, thorium, and potassium. The induction tool has been useful in distinguishing between formation conductivity and resistivity. The three-armed caliper measures unevenness of the borehole wall, and the data are useful during well design and construction. On six different dates, natural gamma, induction, video, and/or caliper logs were run in either the borehole or the installed well at R-32 using down-hole logging tools provided by the Laboratory. Three natural gamma logs were run. The first two provided lithologic and stratigraphic information to complement data gathered from cuttings, and the third verified well installation details. An induction log was run in conjunction with the first two natural gamma logs. Additionally, a caliper log was collected for the open portion of the borehole to TD. Six video logs were collected to record lithologic and hydrogeologic features and to observe and document the condition of the interior of the well near the end of development. Subcontractor personnel trained to use Laboratory-owned tools performed the down-hole logging. The video log tapes of the open borehole are presented in Appendix D (see CD attached to the inside back cover of this report).

The first gamma log and induction logs were run in conjunction with the first induction log, prior to installation of the 11.75-in. thin-walled steel-conductor casing. At that time, an 18-in. surface casing was in place from the surface to 54.5 ft bgs, and the borehole was open from 54.5 to 808 ft bgs. The second gamma log was also run in conjunction with an induction log. At that time, the 18-in. surface casing was still in place, and logging was conducted inside the 11.75-in. conductor casing from ground surface to 797.3 ft bgs and in the open borehole from 797.3 to 1008 ft bgs. The third gamma log was run inside the installed well to a depth of 1002 ft bgs to verify placement of annular backfill materials and to document features of the constructed well. For all gamma logs, measurements of natural gamma activity were obtained every 0.1 ft as the logging tool was raised in the hole at a rate of about 15 ft/min.

The first video log was run through the entire depth of the Phase I borehole to document sidewall features after coring operations were complete. The borehole was cased from the surface to 59.1 ft bgs and open from 59.1 to 318 ft bgs. The next two video logs were run in the Phase II borehole before each of the natural gamma logs to evaluate sidewall stability before deploying the natural gamma and induction logging tools (Table 5.0-1). This video logging also was run to record stratigraphic, geologic, and hydrologic features visible in the open portion of the borehole. Three additional video logs were run in the completed well as a quality control procedure to verify well construction and inspect the condition of casing and screens. In addition, a video log was run to assess water clarity in the well during development but before the Westbay™ multiport system was installed.

## 5.2 Schlumberger Geophysical Logging

Schlumberger conducted borehole geophysical logging on July 31, 2002, in R-32 (Table 5.0-1). The entire suite of logging surveys was run prior to installation of the 11.75-in., thin-walled, steel-conductor casing. At that time, 18-in. surface casing extended from the surface to 54.5 ft bgs, and the borehole was open from 54.5 to 808 ft bgs.

The primary purpose of the Schlumberger logging was to (1) characterize conditions in the hydrogeologic units that were penetrated by the borehole in order to determine moisture distribution in the vadose zone and porosity in the regional aquifer, (2) provide data to aid in identifying transmissive zones, and (3) obtain lithologic and stratigraphic data. Secondary objectives included evaluating borehole geometry and the degree of drilling fluid invasion along the borehole wall.

The Schlumberger suite of geophysical logging tools included the following:

- Array Induction Tool, Version H (AITH™) measures electrical resistivity of the formation, assesses borehole fluid resistivity, evaluates drilling fluid invasion into the formation, and aids in detecting moist zones far from the borehole wall.
- Combinable Magnetic Resonance (CMR™) measures the nuclear magnetic resonance response of the formation, evaluates total and effective water-filled porosity of the host rock near the borehole wall, and estimates size distribution of water-filled pores and hydraulic conductivity of saturated intervals.
- Triple detector LithoDensity (TLD™) measures total porosity and bulk density of a formation, assesses photoelectric effects, measures borehole diameter, and assists in characterizing lithology.
- Thermal/Epithermal Compensated Neutron Tool, Model G (CNTG™) assists in characterizing volumetric water content beyond the casing to evaluate formation moisture content and porosity.

- Natural Gamma Spectroscopy (NGS™) measures gross natural and spectral gamma ray activity (including potassium, thorium, and uranium concentrations) in open- and cased-hole conditions to help characterize geology and lithology.
- Elemental Capture Sonde (ECS™) measures elemental weight concentrations of a variety of elements to aid in characterizing formation mineralogy, lithology, and water content.

Additionally, a calibrated natural gamma tool was used to record gross natural gamma activity with every logging method (except NGS™) to correlate depth runs between each survey conducted.

The Schlumberger logging summary report and montage files for borehole R-32 are presented in Appendix E (on a CD attached to the inside back cover of this report).

## **6.0 LITHOLOGY AND HYDROGEOLOGY**

A preliminary assessment of the hydrogeologic features encountered during drilling of borehole R-32 is presented below, including a description of the geologic units identified during characterization of core and cuttings. Groundwater occurrences are discussed based on drilling evidence and Schlumberger summaries of geophysical logging.

### **6.1 Stratigraphy and Lithologic Logging**

Rock units and stratigraphic relationships, interpreted primarily from visual examination of drilling samples and interpretation of geophysical data, are discussed briefly in order of younger to older units encountered. These interpretations may be refined upon further analysis of petrographic, geochemical, mineralogical, and geophysical logging data. Core samples were examined to describe the interval from ground surface to 318 ft bgs, and drill cuttings were examined to describe the interval from 318 ft to 915.5 ft bgs. Because of drilling-fluid circulation loss, no cuttings were recovered from 915.5 ft bgs to the borehole TD of 1008 ft bgs. A field-generated lithology log is attached as Appendix C.

#### **Alluvium (0 to 47 ft bgs)**

Unconsolidated tuffaceous gravels and sands with a clayey matrix were noted in the interval from 0 to 47 ft bgs. Gravel, up to cobble size, consists predominantly of Tshicoma-type dacites. Sand-sized detritus, mostly quartz and sanidine crystal grains, are derived from the Bandelier Tuff. These sediments represent alluvial deposits in the Pajarito Canyon stream channel.

#### **Bandelier Tuff (47 to 287 ft bgs)**

Quaternary-age Bandelier Tuff was encountered in the interval from 47 to 287 ft bgs. Units of the Bandelier Tuff included the Tshirege and Otowi Members. Volcaniclastic sedimentary deposits of the Cerro Toledo interval are intercalated between two members of the Bandelier Tuff.

#### **Tshirege Member of the Bandelier Tuff (47 to 138 ft bgs)**

The Tshirege Member of the Bandelier Tuff was encountered in the interval from 47 to 138 ft bgs. Core samples indicate that this section of the Tshirege Member is pumice-rich, with pumice lapilli up to 4 cm long, making up approximately 25 to 50% of the rock by volume. Pumices generally have a fibrous texture but include varieties with a sugary texture in areas of devitrification. Phenocrysts of quartz and sanidine occur in abundances up to 12% of the tuff by volume, and volcanic xenoliths (mostly dacite) make up less

than 2% of the tuff. The tuff matrix is nonwelded and consists of ash, pumice, crystals, glass shards, and xenoliths.

#### **Cerro Toledo Interval (138 to 174 ft bgs)**

The Cerro Toledo interval was encountered from 138 to 174 ft bgs in R-32. Core samples show that the Cerro Toledo is composed of pumiceous gravels and sands. Subangular to subrounded cobble-sized clasts of dacite were noted. Sand-sized detritus is composed predominantly of quartz and sanidine crystal grains, with lesser pumice and volcanic lithic fragments.

#### **Ash Flows of the Otowi Member of the Bandelier Tuff (174 to 277 ft bgs)**

Pale yellowish-brown nonwelded to slightly welded rhyolite ash-flow tuff of the Otowi Member of the Bandelier Tuff was encountered from 174 to 277 ft bgs. Core samples indicate that this section of the Otowi Member is pumice-rich. Pumices are generally glassy with a fibrous texture, but become altered in the lower part of the section. Black-to-red lithic fragments, mostly dacitic, make up approximately 20% of the tuff by volume, and phenocrysts of quartz and sanidine occur in abundances up to approximately 15% of the tuff. The tuff matrix is composed of nonwelded to slightly welded vitric ash containing numerous glass shards.

#### **Guaje Pumice Bed of the Otowi Member, Bandelier Tuff (277 to 287 ft bgs)**

The Guaje Pumice Bed was encountered from 277 to 287 ft bgs. Core samples from this interval show that the unit is locally nonwelded and composed of approximately 75% glassy, somewhat fibrous, and partly altered pumice. Small black, gray, and red dacite lithic fragments and quartz and sanidine crystals make up approximately 5% of this unit by volume. The pumice, crystals, and lithics are enclosed in a nonwelded matrix of vitric ash and glass shards. A moderately brown silty sand containing scoriaceous basalt gravel underlies the base of the Guaje Pumice Bed. This layer is interpreted as a paleosol that formed above the underlying basalt.

#### **Cerros del Rio Basalt and Associated Deposits (287 to 923 ft bgs)**

The R-32 borehole intersected basaltic lavas, scoria deposits, and volcanoclastic sediments of the Cerros del Rio volcanic field from 287 to 915.5 ft bgs. Because of fluid circulation loss during drilling, no sample cuttings were produced from 915.5 to 1008 ft bgs. Preliminary interpretation of geophysical logging data indicates that the base of the Cerros del Rio basalt section lies at 923 ft bgs.

Cuttings samples suggest that the upper part of the Cerros del Rio basalt section, from 287 to 658 ft bgs, consists of a series of massive basalt lavas separated by intervals of highly vesicular to scoriaceous basalt. Six or more individual flows, some up to 75 ft thick, may be present. Intercalated intervals of reddish-colored scoria are as much as 20 ft thick. Basalt lavas exhibit sparsely porphyritic textures with an aphanitic groundmass and contain up to 5% phenocrysts of olivine and minor plagioclase. The groundmass, in both massive and vesicular basalt, is partially to pervasively altered. Olivine in the scoriaceous intervals generally is oxidized or replaced by iddingsite, whereas olivine in the massive basalts is mostly unaltered. Secondary clays, abundant in the scoriaceous basalt, are confined to coatings on fractures or to the linings of vesicles in the massive basalt.

The lower part of the Cerros del Rio basalt section, from 658 to 923 ft bgs, is made up of basalt lava flows, basaltic scoria, and interbedded clastic sediments. Discrete lava flows are poorly defined. Cuttings samples frequently contain both basalt chips and sedimentary detritus. Basalt in this section is sparsely

porphyritic, containing only minor olivine as phenocrysts, or phenocrysts are absent altogether. Sedimentary clasts derived from varied lithologies include quartzite, potassium feldspar, granite, and diverse volcanic lithics, as well as significant amounts (up to 50%) of limonite-stained volcanoclastic sandstone fragments, were noted in cuttings samples from 863 to 915.5 ft bgs. Many clasts exhibited some degree of rounding, indicating the presence of possible sedimentary units in this interval. The interval from 863 to 870 ft bgs has been interpreted as deposits of river gravel.

### **Puye Formation (923 to 1008 ft bgs)**

The Puye Formation is composed of alluvial-fan deposits (Griggs and Hem 1964, 0313) that are widely distributed in the investigation area. These sediments are dominantly composed of intermediate-composition volcanic rock debris shed from the Jemez Mountains but also can include, to varying degrees, detrital quartzite and other lithics derived from Precambrian sources.

Because drilling-fluid circulation was lost, no cuttings were returned from about 916 ft to TD at 1008 ft bgs. The geophysical logging data, however, suggest that the Puye Formation occurs from 923 to 1008 ft bgs in R-32.

## **6.2 Groundwater Occurrence and Characteristics**

Perched zones of saturation were anticipated at R-32. This includes both water perched at shallow depth in the alluvium forming the canyon floor and water perched at intermediate depth in various geologic units between the surface and the regional water table. Water was encountered during drilling in the alluvium at a depth of 22 ft bgs. This water is perched atop the less-permeable Tshirege Member of the Bandelier Tuff, which underlies the alluvium. No intermediate-depth perched water was identified. However, drilling in the vadose zone was conducted by the air-rotary method with foam additives. This method substantially reduces the ability to detect local perched zones of saturation, unless they are thick and unusually productive.

The regional water table, which was predicted to occur at approximately 856 ft bgs (LANL 2002, 73390), was first encountered in the open borehole and measured on August 1, 2002, at 738.5 ft bgs in the Cerros del Rio basalt after the borehole had been drilled to 808 ft bgs and the water level was allowed to stabilize. When the measurement was made, only the surface casing was in place to 54.5 ft bgs. The static water level was measured at 725.6 ft bgs on August 8, 2002, after the borehole had been drilled to 1008 ft bgs and allowed to stabilize. On November 12, 2002, after well development was completed but before installation of the Westbay™ system, a composite static water level in the completed well was measured at 783.4 ft bgs.

## **7.0 WELL DESIGN AND CONSTRUCTION**

Sections 7.1 and 7.2 describe the R-32 well design and construction, respectively.

### **7.1 Well Design**

The R-32 well design was completed jointly by the Laboratory and WGII, in consultation with the US Department of Energy and the New Mexico Environment Department (NMED). Geophysical logs, video logs, borehole geologic samples, water-level data, field water-quality data, and drillers' observations were reviewed by the Groundwater Integration Team to plan screen placement intervals for the well.

The final well design specified three screens to monitor water levels, determine vertical hydraulic gradients, and characterize water quality in the regional aquifer. The planned and actual screen intervals are given in Table 7.1-1.

**Table 7.1-1  
Summary of Well Screen Information, Characterization Well R-32**

| Screen | Planned Depth (ft) | Actual Depth (ft) | Geologic/Hydrologic Setting   |
|--------|--------------------|-------------------|---|
| 1      | 867.7–874.5        | 867.5–875.2       | Within the regional aquifer in river gravels above Cerros del Rio basalt          |
| 2      | 930.7–933.5        | 931.8–934.9       | Within the uppermost part of the Puye Formation in the regional aquifer           |
| 3      | 970.8–977.6        | 972.9–980.6       | Within the deepest part of the Puye Formation that was penetrated by the borehole |

## 7.2 Well Construction

Well casing and pipe-based screens for well R-32 were manufactured using 4.5-in. inner diameter (ID)/5.0-in. outer diameter (OD), type 304 stainless steel fabricated to American Society for Testing and Materials (ASTM) standard A554. External couplings were also type 304 stainless steel fabricated to ASTM standards A312 and A511, both of which exceed the tensile strength of the threaded casing ends. The pipe-based screens were modified from 10-ft sections of blank well casing by drilling 0.5-in.-diameter holes (168 holes/ft) and then welding a stainless steel wire-wrap (with 0.010-in. spacing) over the perforated interval. The final OD of the screened sections was 5.56 in.

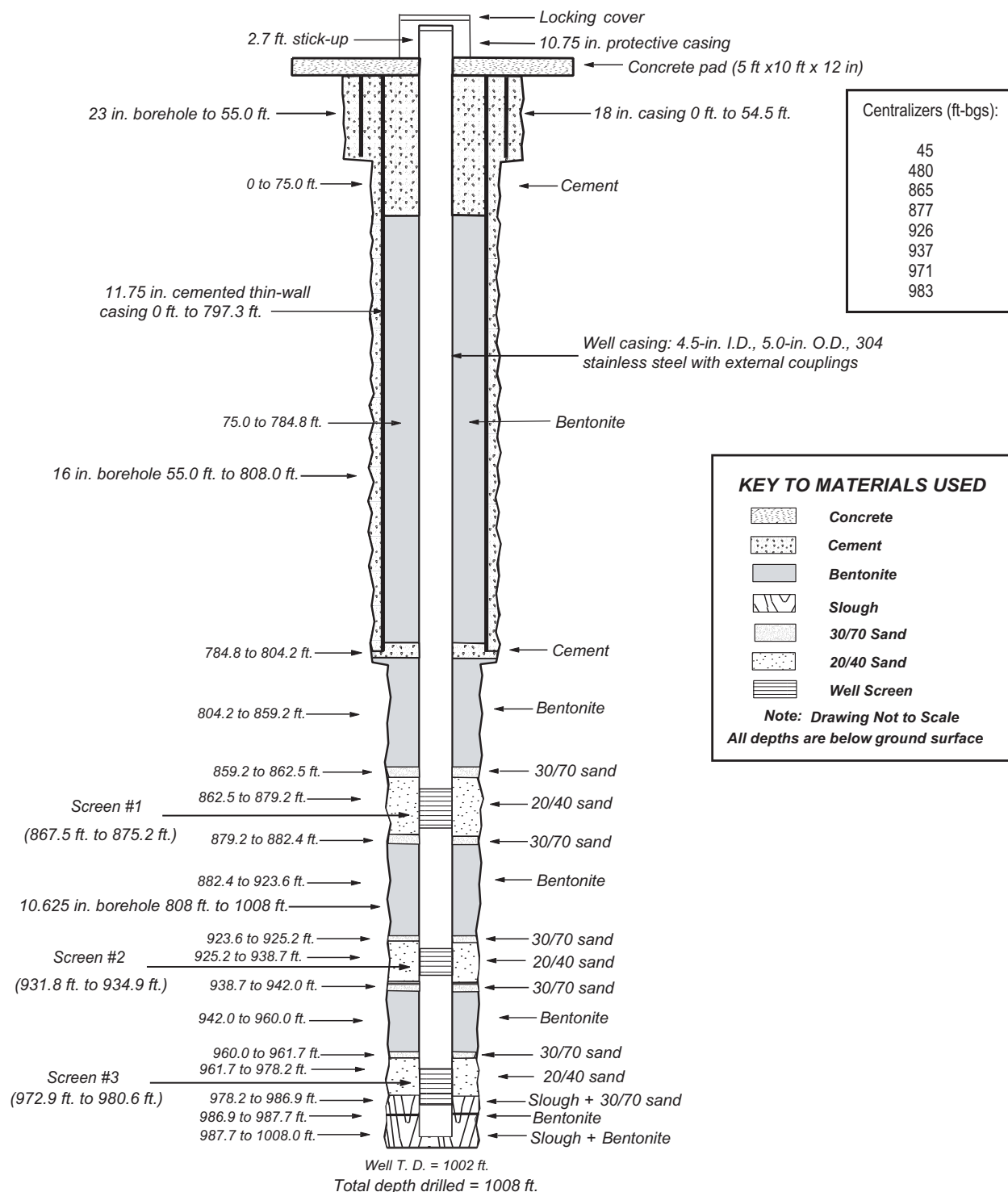
All stainless steel well components were cleaned at the well site using a steam cleaner and scrub brushes. All annular fill materials were placed in the well casing/borehole annulus through a tremie pipe. Well construction activities were completed between August 8 and 12, 2002 (Figure 3.0-2).

### 7.2.1 Well Steel Installation

Dynatec installed the R-32 well casing and screens on August 9, 2002. Figure 7.2-1 shows the as-built well casing configuration and indicates the depths of the various well components from ground surface. Well steel installation consisted of connecting joints of stainless steel well casing and screen sections by means of threaded couplings. The bottom of the well was set at 1002 ft bgs. Stainless steel centralizers were installed above and below each screen and in several locations above the zone of regional saturation to centralize the well within the borehole during and after backfill placement operations.

### 7.2.2 Annular Fill Placement

Placement of annular fill consisted of using a steel tremie pipe to deliver annular materials to the specified depths (Figure 7.2-1). Filter packs across screened intervals consisted of silica sand materials mixed with municipal water. Bentonite materials were placed between screened intervals to seal the annular space and isolate the water-bearing zones. Portland® cement (mixed at a ratio of 5 gal. of water to each bag of cement) was used to provide a foundation for the annular fill above the regional aquifer and to protect the annular space around the wellhead in the upper 75 ft of the borehole. Approximately 12,200 gal. of municipal water were used during placement of annular fill material.



- Note:
1. Each screen interval lists the footage of the pipe perforations, not the top and bottom of screen joints.
  2. The interval of slough probably consist of sands and gravel of the Puye Formation.
  3. Westbay multiport sampling system (MP-55) casing not shown.
  4. Pipe-based screen: 4.5-in. I.D., 5.563-in. O.D., 304 stainless steel with s.s. wire wrap; 0.010-in. slot.
  5. Well sump interval: 980.6 to 1002 ft.

**Figure 7.2.1. As-built well configuration diagram, characterization well R-32**

Dynatec performed placement activities from August 9 through 12, 2002. Table 7.2-1 summarizes the annular fill materials used. The final configuration of annular materials is shown in Figure 7.2-1.

**Table 7.2-1**  
**Annular Fill Materials, Characterization Well R-32**

| Material  | Use/Function   | Amount | Unit*  |
|---|--|--------|--------|
| 20/40 sand (medium-grained)   | To pack screen intervals   | 47     | bag    |
| 30/70 sand (fine-grained)   | To separate filter packs from bentonite seals                                    | 16     | bag    |
| QUICK-GROUT®  | High-solids bentonite grout used for seals                                       | 80     | bag    |
| Pelplug® bentonite (0.25 in. by .375 in., refined elliptical pellets)             | To provide borehole annular seal below the water table                           | 95     | bucket |
| Portland® cement (mixed with municipal water at a ratio of 5 gal. water to 1 bag) | To provide annular support and surface seal on the upper portion of the borehole | 44     | bag    |

\*Sand bag = 50 lb ea, bentonite bag/bucket = 50 lb ea, cement bag = 94 lb ea.

## 8.0 WELL DEVELOPMENT AND HYDROLOGIC TESTING

Well development and hydrologic testing activities at R-32 were conducted between August 15 and November 10, 2002 (Figure 3.0-2). Well development procedures included wire-brushing, surging, bailing, chemical treatment of well screens, and development pumping. Development activities were followed by hydrologic tests conducted at screens 1 and 3.

### 8.1 Well Development

Well development was carried out using a variety of methods. The initial stage consisted of wire brushing the well interior, surging to draw fine sediment from the constructed filter packs, and bailing to remove unwanted solid materials from the well. In addition, the well was pumped to remove any remaining fines from the filter pack and adjacent formation. As part of development, chemical treatments were applied to the well screens to break up borehole wall filter cake and disperse particulate matter that resulted from adding drilling fluids during conventional mud-rotary drilling.

Well-development criteria were based on selected field water-quality parameters (turbidity, specific conductance, pH, and temperature). To monitor progress during development, samples of purged groundwater were collected periodically and the parameters were measured. A primary objective of well development was to remove suspended sediment from the water until turbidity decreased to a value less than 5 nephelometric turbidity units (NTUs) for three consecutive samples. Similarly, other measured parameters were required to stabilize before development could be terminated. The well was declared sufficiently developed when the required criteria were met or could not be improved with continued pumping. Table 8.1-1 presents pumping and water-quality parameter measurements recorded at the beginning and end of selected well development methods.

**Table 8.1-1**  
**Development of Characterization Well R-32**

| Method   | Water Produced (gal.) | Range of Parameters <sup>a</sup> |                  |   |                 |
|--|-----------------------|----------------------------------|------------------|---|-----------------|
|  |                       | pH                               | Temperature (°C) | Specific Conductance (μS/cm) <sup>b</sup> | Turbidity (NTU) |
| Preliminary bailing/wire brushing/surging                                      | 8240                  | 9.0–8.6                          | 22.6–20.5        | 656–215                                   | >1000–110       |
| Pump   | 6015                  | 7.6–8.2                          | 16.9–21.4        | 302–185                                   | 109–11.4        |
| Chemical treatment (400 gal. of AQ-PFD)  | +400                  | — <sup>c</sup>                   | —                | —   | —               |
| Surging/bailing  | 1160                  | 9.7–8.8                          | 18.8–20.2        | 1390–236                                  | 90.1–132        |
| Chemical treatment (330 gal. AQ-MGA <sup>d</sup> and -AE <sup>e</sup> to well) | +330                  | —                                | —                | —   | —               |
| Surging/bailing  | 1900                  | 2–7                              | 19.6             | 341                                       | 12              |
| Pump   | 66,110                | 7.2–6.8                          | 21.2–21.2        | 306–172                                   | 19–2.4          |
| Pumping screen 3 w/packers   | 24,810                | 6.8–6.8                          | 23.1–22.4        | 103–97                                    | 2.4–1.9         |
| Pumping at screen 2 w/packers  | 3015                  | 7.2–6.8                          | 19.9–23.6        | 110–143                                   | 42.2–3.3        |
| Pumping at screen 1 w/packers  | 4450                  | 7.3–6.9                          | 22.7–24.4        | 115–251                                   | 5.7–3.7         |
| TOTAL  | 114,970               |                                  |                  |   |                 |

<sup>a</sup> Parameters presented as value at beginning followed by value at end of development method.

<sup>b</sup> Specific conductance reported in microsiemens per centimeter (μS/cm).

<sup>c</sup> — = No samples collected.

<sup>d</sup> MGA = modified granular acid.

<sup>e</sup> AE = acid enhancer.

Development of the R-32 well began on August 18, 2002. The casing and screens were cleaned using a wire-brush system to remove any materials that may have been introduced into the well interior during construction. Surging techniques then were used across all three screens with a wire-line-controlled surge block for rapid upward-downward strokes. Between August 18 and 29, 2002, the well screens were surged repeatedly, followed by periods of bailing. Water turbidity exceeded 1000 NTU during early surging/bailing procedures and decreased to 110 NTU after an estimated 8240 gal. of water were bailed (Table 8.1-1).

Development by pumping began on September 1, 2002. Pumping initially was conducted from all screens without the assistance of inflatable packers. A 10-horsepower (hp) submersible pump was lowered to the bottom of screen 3 and on/off cyclic pumping was conducted with approximately 30-min. periods of nonpumping to allow water levels in the well to recover. A total of 6015 gal. of groundwater was removed. Initially turbidity was measured at 109 NTU and decreased to 11.4 NTU during the pumping phase.

Well development was assisted by chemical treatments of the screens to break up and remove drilling-mud filter-cake build-up on the borehole wall during conventional mud-rotary drilling. Chemical treatments, along with surge/bail procedures, were performed between September 12 and 23, 2002. Initially, a mixture of 1 gal. of AQUACLEAR<sup>TM</sup>-PFD (phosphate-free dispersant) and 400 gal. of municipal

water were pumped into the well and surged into all three screens. Following surging and bailing, a solution containing 90 lb of AQUA-CLEAR™- MGA (modified granular acid) and 9 gal. of AQUA-CLEAR™-AE (acid enhancer) and 330 gal. of municipal water were mixed on the site, pumped into the well, and surged into all three screens. Development pumping on screen 3 resumed from September 25 to October 2, 2002. Pumping with packers positioned above and below each screen to isolate the water-bearing zone was carried out from October 22 to October 31, 2002. As indicated in Table 8.1-1, turbidity measurements decreased to less than 5 NTU at each screen interval at the end of the pumping periods for each screen. Approximately 144,600 gal. of water were purged during development.

## **8.2 Hydrologic Testing**

On November 4 and 5, 2002, the Laboratory conducted injection tests of saturated materials behind screens 1 and 3 in well R-32. The injection assembly, consisting of two inflatable packers separated by a perforated pipe, was positioned around each screen. For a given screen, the water-level response to injecting municipal water at different rates for different periods of time was monitored with a pressure transducer. Specifically, three tests were conducted at screens 1 and 3. During testing, 990 gal. of water were injected into the well. Following testing, 28,920 gal. of water were purged from the well. Results of these tests, as well as details of their design, implementation, and analysis, will be presented in a separate Laboratory report.

## **8.3 Installation of Westbay™ Monitoring System**

A Westbay™ sampling system was installed inside the stainless steel well casing after development procedures were completed. The base of the multiport casing was set at 998.5 ft bgs. The system was set in place using a series of packers inflated with deionized water and positioned to target each well screen with a set of valved ports. The R-32 system contains six ports used to monitor and test nine packers. Screens 1 and 3 are accessed by two measurement ports and screen 2 by one measurement port. Measurement zones 1 and 3 also contain a pumping port. Quarterly sampling of Westbay™-equipped wells was done using a Laboratory-owned sampling trailer equipped with a MOSDAX® sampling system (controller, sampler probe, and sample bottle train) and a motorized winch and boom system. The Westbay™ summary MP casing log provides details of the installed system (Appendix F).

## **9.0 WELLHEAD COMPLETION AND SITE RESTORATION**

After completion of Westbay™ installation, finish work commenced on the wellhead area. Well components were surveyed, and the site underwent final cleanup and restoration.

### **9.1 Wellhead Completion**

The surface completion for well R-32 involved construction of a reinforced (3000 pounds per square inch [psi]) concrete pad, 5-ft-wide by 10-ft-long by 12-in.-thick, around the well casing to ensure the long-term structural integrity of the well (Figure 9.1-1). The concrete pad was poured on December 12, 2002. A brass survey cap was installed in the northwest corner of the pad. The pad was designed to be slightly elevated, with base-course gravel graded up around the pad to allow drainage. A 10.75-in.-diameter steel casing with locking lid was installed to protect the well riser. Four 4-in.-diameter steel bollards were placed around the pad, one next to each side. One bollard can be removable to allow access to the well for sampling and maintenance.

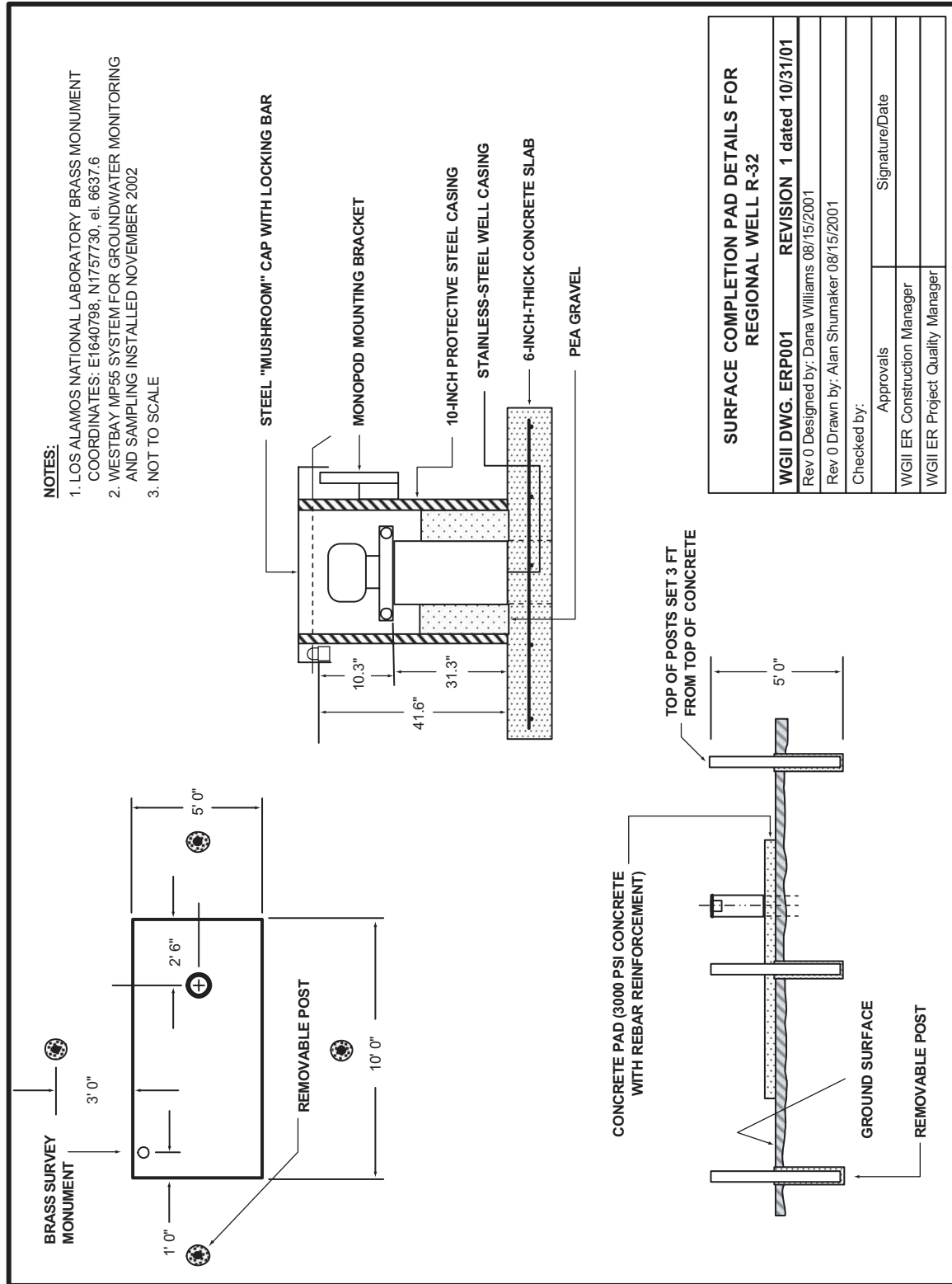


Figure 9.1-1. Surface completion configuration diagram, characterization well R-32

## 9.2 Geodetic Survey

Southwest Mountain Surveys, Inc. (NMPLS #6998) conducted a geodetic survey of well R-32 on December 19, 2002, using a global positioning satellite (GPS) system. The GPS system uses National Geodetic Vertical Datum of 99/96 for vertical computations and the datum for the horizontal control network is North American Datum 1983 (NAD 83). The survey located the brass monument in the northwest corner of the concrete pad and measured location and elevation at the top of the steel protective casing, the top of the Westbay™ cap, and the top of the Westbay™ plate (Table 9.2-1). The coordinates shown are in New Mexico State Plane coordinates, Central Zone (NAD 83) expressed in feet. To be consistent with current Laboratory standards, elevations are expressed in feet above mean sea level and referenced to the National Geodetic Vertical Datum of 1929 (NGVD29).

**Table 9.2-1**  
**Geodetic Data, Characterization Well R-32**

| Description                         | East       | North      | Elevation |
|-------------------------------------|------------|------------|-----------|
| Brass cap in R-32 pad               | 1640797.67 | 1757730.25 | 6637.63   |
| Top of protective steel well casing | 1640797.66 | 1757728.50 | 6640.47   |
| Top of Westbay™ cap                 | 1640797.84 | 1757728.48 | 6640.88   |
| Top of Westbay™ plate               | 1640797.58 | 1757728.70 | 6641.18   |

## 9.3 Site Restoration

Site restoration activities at R-32 were conducted by K. R. Swerdfeger Construction, Inc., from February 24 to March 6, 2003 (Figure 3.0-2). Prior to and along with restoration, waste management activities were also performed. Waste materials were removed from the site as specified in the WCSF. Drilling activity media included drilling fluids, cuttings, and development water, that were sampled for contaminant analysis (Appendix G). After the Laboratory and NMED reviewed the test data, the fluids were approved for land application. The drill cuttings were used to help backfill the cuttings-containment area; the drilling fluids and development water were applied around the site with a 3-in.-pipe irrigation system as specified in the Notice of Intent. Waste streams from minor spill cleanup included petroleum-contaminated soils and absorbent materials used during cleanup. After the Laboratory approved the waste profile forms, the waste streams were disposed of as New Mexico Special Waste. Before the site was graded, the cuttings-containment area was excavated and the plastic lining was removed. The cuttings-containment area then was backfilled with drill cuttings and dirt that had been bermed during pad construction and the area was regraded. Base-course gravel was also regraded and compacted across the site to form a smaller pad. The site was re-seeded with a blend of native grasses mixed with fertilizer to facilitate regrowth of ground cover.

## 10.0 DEVIATIONS FROM THE R-32 SAP

- *Planned depth.* Well R-32 was drilled to 1008 ft bgs rather than to the planned depth of 1356 ft bgs. The decision to terminate drilling was based on the potential loss of the borehole if circulation could not be re-established. The final depth maintained the original goal of drilling to 100 to 500 ft beneath the regional water level.
- *Laboratory tests of hydraulic properties.* Core samples were not selected for hydraulic property tests because of poor core quality and insufficient core size for meaningful test results.

## 11.0 ACKNOWLEDGEMENTS

Dynatec Drilling Company provided rotary drilling services.

Tetra-Tech EM, Inc.; D. B. Stephens and Associates, Inc.; and S. M. Stoller provided support for well-site geology, sample collection, and hydrologic testing.

Southwest Mountain Surveys, Inc. (NMPLS #6998), provided the final geodetic survey of finished well components.

D. Thompson and C. Schultz of PMC Technologies (Exton, Pennsylvania) and P. Schuh, E. Tow, and R. Lawrence of Tetra-Tech EM, Inc. (Albuquerque, New Mexico), contributed to the preparation of this report.

R. Bohn and E. Louderbough of Los Alamos National Laboratory reviewed this report for classification and legal purposes, respectively.

D. Broxton, P. Longmire, S. Pearson, W. Stone, and D. Vaniman, of Los Alamos National Laboratory, prepared this report.

Schlumberger Integrated Water Solutions provided processing and interpretation of borehole geophysical data.

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## **Appendix A**

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*Activities Planned for R-32 Compared with Work Performed*

| Activity   | "Hydrogeologic Workplan"<br>(LANL 1998, 59599)  | R-32 Sampling and Analysis<br>Plan (LANL 2002, 73390)  | R-32 Actual Work   |
|--|---|--|--|
| Planned Depth  | 100 to 500 ft into the regional aquifer   | Estimated depth of 1356 ft below ground surface (bgs)  | Total drill depth 1008 ft bgs  |
| Drilling Method  | Methods may include, but are not limited to hollow-stem auger (HAS), air-rotary/Odex, air-rotary/Barber rig, and mud-rotary drilling  | Stiff-foam, air-rotary, air rotary, mud rotary, flooded-reverse circulation, and fluid-assist air-rotary with casing-advance   | Air-rotary core with wire-line retrieval and conventional mud rotary   |
| Amount of Core   | 10% of the borehole   | Continuous core from surface to estimated depth of 344 ft, but no deeper than 400 ft bgs   | Continuous core from surface to 318 ft bgs   |
| Lithologic Log   | Log to be prepared from core, cuttings, and drilling performance data   | Log to be prepared from core, cuttings, geophysical logs, and drilling performance data  | Log prepared from core, cuttings, geophysical logs, and drilling performance data  |
| Number of Water Samples Collected for Contaminant Analysis | A water sample may be collected from each saturated zone, five zones assumed. The number of sampling events after well completion is not specified.   | If perched water is encountered within the bedrock units of the unsaturated zone, one groundwater-screening sample will be collected within up to three perched zones.<br><br>Groundwater-screening samples will be collected within the regional aquifer at the regional water table and at the total depth (TD) of the borehole.   | No perched water was identified during drilling  |
| Water Sample Analysis                                      | Initial sampling: radiochemistry I, II, and III, tritium, general inorganics, stable isotopes, volatile organic compounds (VOCs), and metals.<br><br>Saturated zones: radionuclides (tritium, <sup>90</sup> Sr, <sup>137</sup> Cs, <sup>241</sup> Am, plutonium isotopes, uranium isotopes, gamma spectrometry, and gross alpha, beta, and gamma), stable isotopes (hydrogen, oxygen, and in special cases nitrogen), major ions (cations and anions), trace metals, and trace elements | Metals (dissolved), anions (dissolved), VOCs, <sup>99</sup> Tc, gamma spec, <sup>241</sup> Am, <sup>137</sup> Cs, <sup>238</sup> Pu, <sup>239,240</sup> Pu, <sup>234</sup> U, <sup>235</sup> U, <sup>238</sup> U, <sup>90</sup> Sr, stable isotopes ( <sup>18</sup> O/ <sup>16</sup> O, D/H, <sup>15</sup> N/ <sup>14</sup> N), tritium, tritium (low level or direct counting), radiological screening (gross-alpha, beta, gamma) | At the start of well development a groundwater sample was bailed from the bottom of the well and analyzed for metals (dissolved) including total U and anions (dissolved). Following well completion and development, groundwater samples, from screens 1, 2, and 3 were analyzed for metals (dissolved), anions (dissolved), VOCs, gamma spectrometry, radionuclides ( <sup>99</sup> Tc, <sup>241</sup> Am, <sup>238</sup> Pu, <sup>239,240</sup> Pu, <sup>234</sup> U, <sup>235</sup> U, <sup>238</sup> U, <sup>90</sup> Sr), stable isotopes ( <sup>18</sup> O/ <sup>16</sup> O, D/H, <sup>15</sup> N/ <sup>14</sup> N), tritium, tritium (low level or direct counting), U-total, perchlorate, alkalinity, and radiological screening (gross-alpha, beta, gamma) |
| Water Sample Field Measurements                            | Alkalinity, pH, specific conductance, temperature, turbidity  | Alkalinity, pH, specific conductance, temperature, turbidity   | pH, specific conductance, temperature, turbidity   |

| Activity   | "Hydrogeologic Workplan"<br>(LANL 1998, 59599)   | R-32 Sampling and Analysis<br>Plan (LANL 2002, 73390)  | R-32 Actual Work   |
|--|--|--|--|
| Number of Core/Cuttings Samples Collected for Contaminant Analysis | Twenty samples of core or cuttings to be analyzed for potential contaminant identification in each borehole.   | A minimum of two core/cuttings samples will be collected for geochemical and contaminant characterization within water-bearing zones, if possible, encountered during drilling.  | Thirteen core/cuttings samples submitted for analysis  |
| Core/Cuttings Sample Analytes                                      | Upper-most core or cuttings sample to be analyzed for a full range of compounds; deeper samples will be analyzed for the presence of radiochemistry I, II, and III analytes, tritium (low- and high-detection levels), and metals. Four samples to be analyzed for VOCs. | Analytical suite for cuttings samples includes anions, stable isotopes, VOCs, tritium profiles, perchlorate, radionuclides ( $^{241}\text{Am}$ , $^{238}\text{Pu}$ , $^{239,240}\text{Pu}$ , $^{234}\text{U}$ , $^{235}\text{U}$ , $^{238}\text{U}$ , $^{90}\text{Sr}$ ) gamma spectroscopy, radiological screening (gross alpha, beta, and gamma), radionuclides, and metals. | Analytical suite for core samples included anions, stable isotopes, tritium profiles, radionuclides ( $^{241}\text{Am}$ , $^{238}\text{Pu}$ , $^{239,240}\text{Pu}$ , $^{234}\text{U}$ , $^{235}\text{U}$ , $^{238}\text{U}$ , $^{90}\text{Sr}$ ) gamma spectroscopy, radiological screening (gross alpha, beta, and gamma), and metals. |
| Laboratory Hydraulic-Property Tests                                | Physical properties analyses will be conducted on 5 core samples and will typically include moisture content, porosity, particle density, bulk density, saturated hydraulic conductivity, and water retention characteristics.   | Physical properties analyses will be conducted on core sample for moisture content.  | No analyses were performed.  |
| Geology  | Ten samples of core or cuttings will be collected for petrographic, X-ray fluorescence (XRF) and X-ray diffraction (XRD) analyses.   | Analytical testing of samples may include mineralogy by XRD, petrography by modal analysis of thin sections, by electron microprobe, and/or by scanning electron microscope, and geochemistry by XRF.  | Samples were collected for mineralogic, petrographic, and chemical analysis at a later date.   |

| Activity                       | "Hydrogeologic Workplan"<br>(LANL 1998, 59599)   | R-32 Sampling and Analysis<br>Plan (LANL 2002, 73390)   | R-32 Actual Work   |
|--------------------------------|--|---|--|
| Geophysics                     | <p>In general, open-hole geophysics includes caliper, electromagnetic induction, natural gamma, magnetic susceptibility, borehole color videotape (axial and side scan), fluid temperature (saturated), fluid resistivity (saturated), single-point resistivity (saturated), and spontaneous potential (saturated).</p> <p>In general, cased-hole geophysics includes gamma-gamma density, natural gamma, and thermal neutron.</p> | <p>The number and types of logs will vary as function of borehole condition, the presence or absence of drill or well casing.</p> <p>In general, open-hole geophysics includes caliper, array induction, triple lithodensity, combinable magnetic resonance, natural gamma, natural gamma ray spectrometry, epithermal compensated neutron, mechanical sidewall coring tool, fullbore formation microimager, and borehole color videotape (axial and side scan).</p> <p>In general, cased-hole geophysics includes: triple lithodensity, natural gamma ray spectrometry, natural gamma, and epithermal compensated neutron.</p> | <p>LANL tools: 0–54.5 ft bgs (cased), 54.5–720 ft bgs (open hole): Video; 0–54.5 ft bgs (cased), 54.5–1008 ft (open hole): caliper, natural gamma, and induction; 0–1002 ft (within the well): video, natural gamma</p> <p>Schlumberger: geophysics: 0–54.5 ft bgs (cased), 54.5–808 ft bgs (open hole): array induction, combinable magnetic resonance, triple litho density, spectral gamma, elemental capture, and thermal-epithermal neutron</p> |
| Water-Level Measurements       | Procedures and methods not specified in hydrogeologic work plan.   | Water levels will be determined for each saturated zone by water-level meter or by pressure transducer.   | Water-level meter used to determine static water levels at the regional aquifer.   |
| Field Hydraulic-Property Tests | Tests to be conducted not specified in hydrogeologic work plan.  | Straddle-packer/injection tests will be performed in all screens completed below the regional water table.  | Constant rate injection tests were conducted on screens 1 and 3.   |
| Surface Casing                 | Approximately 20-in. outer diameter (OD), extends from land surface to 10-ft depth in underlying competent layer and grouted in place.   | Install 18-in. or 20-in.-OD steel casing to approximately 60 ft.  | 18-in. OD steel casing set at 54.5 ft bgs, cemented in place   |
| Conductor Casing               | Unless other technical methods are applied, a temporary steel casing, up to 14-in.-OD, will be advanced to total depth of borehole.  | Install 11.75-in. OD steel casing from 0 to ~700 to 800 ft bgs, or approximately 100 ft above anticipated regional water level, or; set thin-wall casing over problem zone(s) and seal off casing using standard regulatory procedures.   | 11.75-in. OD drill casing from 0 to 797.3 ft bgs, cemented in place  |
| Minimum Well Casing Size       | 6.625-in. OD   | 5-in. OD  | 5-in.-OD x 4.5-in. inner diameter (ID) stainless steel casing w/ external couplings  |

| Activity  | "Hydrogeologic Workplan"<br>(LANL 1998, 59599)   | R-32 Sampling and Analysis<br>Plan (LANL 2002, 73390)   | R-32 Actual Work  |
|---|--|---|---|
| Well Screen   | Machine-slotted (0.01-in.), stainless steel screens with flush-jointed threads; number and length of screens to be determined on a site-specific basis and proposed to the New Mexico Environment Department (NMED). | Well screen shall be constructed with multiple sections of 5.5-in.-OD stainless steel pipe with wire wrap (0.010-in. slot opening).                                 | Screened intervals constructed of 5.56-in.-OD (4.5-in. ID) pipe based, stainless steel, wire-wrapped, 0.010-in. slotted screen  |
| Filter Material   | >90% silica sand, properly sized for the 0.010-in. slot size of the well screen; extends 2 ft above and below the well screen.   | Filter pack shall extend at least 5 ft and no more than 10 ft above and below each well screen. No distinction was made between primary and secondary filter packs. | Screen 3: Primary filter pack consisted of 20-40 silica sand placed 11.2 ft above screen. Secondary filter pack consisted of 30-70 silica sand in a layer 1.7-ft-thick above and mixed with slough in a layer 8.7-ft-thick across the bottom 1.4 ft of the screen and below.<br><br>Screen 2: Primary filter pack consisted of 20-40 silica sand placed 3.8 ft below and 6.6 ft above screen. Secondary filter pack consisted of 30-70 silica placed in a layer 3.3-ft-thick below and 1.6-ft-thick above.<br><br>Screen 1: Primary filter pack consisted of 20/40 silica sand placed 4 ft below and 5 ft above screen. Secondary filter pack of 30/70 silica sand placed in a layer 3.2-ft thick below and 3.3-ft thick above. |
| Backfill Material<br>(exclusive of<br>filter materials) | Uncontaminated drill cuttings below sump and bentonite above sump  | Bentonite and cement in borehole or well annulus  | Slough and bentonite in borehole and annulus below and around sump from TD to 5.3 ft below top of screen 3. Bentonite seal above screen 3 filter pack and above and below screens 2 and 1 filter packs. Cement plug from 784.8 to 804.2 ft bgs. Cement-bentonite grout from surface to 75 ft bgs.   |
| Sump  | Stainless steel casing with an end cap   | Not specified   | 5-in. diameter stainless steel casing, 20.53-ft long, with an end cap   |
| Bottom Seal   | Bentonite  | Bentonite   | Bentonite   |

## **Appendix B**

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*Drill-Additive Product Specifications  
(CD attached to inside back cover)*

# Appendix C

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*Lithology Log*

| Geologic Unit    | Lithologic Description   | Sample Interval<br>(ft bgs) | Elevation Range<br>(ft above msl) |
|------------------|--|-----------------------------|-----------------------------------|
| Qal,<br>Alluvium | Unconsolidated sediments, sand (SW) with silt, grayish-brown (5YR 3/2), silt to pebble gravel; 10% silt; 88% very fine to fine-grained sand; 2% gravel; poorly sorted, angular grains, unconsolidated. Top 0.6 ft of interval consists of drill pad construction base-course gravel. No core recovered from 0.8 to 1.5 ft bgs.<br>Note: The R-32 borehole was cored from 0 to 318 ft bgs, and lithologic descriptions are from recovered core in this interval. Core recovery was sporadic. Lost core intervals are indicated in the text. Where noted, supplemental samples of drill cuttings were collected and used to characterize the formation in lieu of lost core. | 0–1.5                       | 6637.6–6636.1                     |
|                  | Only 0.4 ft of core recovered from this interval.  | 1.5–4                       | 6636.1–6633.6                     |
|                  | Unconsolidated sediments, gravel (GW) with sand. Cobbles and gravel of rounded dacite (up to 7.0 cm), probably reworked Tschicoma dacite; unconsolidated, dry. No core recovered from 4.2 to 5.0 ft bgs.   | 4–5                         | 6633.6–6632.6                     |
|                  | Unconsolidated sediments, gravel (GW) with sand. Cobbles and gravel of rounded dacite (up to 6.0 cm), probably reworked Tschicoma dacite, unconsolidated. No core recovered from 5.4 to 9.5 ft bgs.  | 5–9.5                       | 6632.6–6628.1                     |
|                  | Unconsolidated sediments, gravel (GW) with sand. Rounded gray dacite gravel (up to 5.0 cm), probably reworked Tschicoma dacite, unconsolidated. No core recovered from 10.0 to 11.5 ft bgs.  | 9.5–11.5                    | 6628.1–6626.1                     |
|                  | No core recovery from this interval.   | 11.5–18                     | 6626.1–6619.6                     |
|                  | Unconsolidated sediments, gravel (GW) with clay and sand, pale brown (5YR 5/2), clay to 5.0 cm dacite gravel, poorly sorted; sand very fine to medium-grained, angular to rounded sand and gravel; fines have moderate plasticity; unconsolidated, saturated. No core recovered from 19.5 to 22.0 ft bgs.  | 18–22                       | 6619.6–6615.6                     |
|                  | No core recovery in this interval.   | 22–26                       | 6615.6–6611.6                     |
|                  | Unconsolidated sediments, gravel (GW) with clay and sand, moderate yellowish-brown (10YR 5/4), clay with cobbles to 7.0 cm, poorly sorted; 10% clay; 20% sand with very fine to coarse-grained, angular grains; 70% rounded to subrounded gravel and cobbles, mostly dacite; unconsolidated, wet. No core recovered from 27.5 to 31.0 ft bgs.  | 26–31                       | 6611.6–6606.6                     |
|                  | Unconsolidated sediments, gravel (GW) with sand, moderate yellowish-brown (10YR 5/4), clay with cobbles to 7.0 cm, poorly sorted; 3% clay; 20% sand, very fine to coarse-grained; 77% rounded to subangular gravel and cobbles, mostly dacite, possibly some basalt; unconsolidated, damp to moist. No core recovered from 32.3 to 36.0 ft bgs.  | 31–36                       | 6606.6–6601.6                     |
|                  | Only 0.2 ft recovered in this interval.  | 36–44                       | 6601.6–6593.6                     |
|                  | Unconsolidated sediments, gravel (GW) with sand. A single rounded dacite cobble (6.0 cm) plugged the core barrel. No core recovered between 44–46 ft bgs.  | 44–46                       | 6593.6–6591.6                     |

| Geologic Unit  | Lithologic Description   | Sample Interval<br>(ft bgs) | Elevation Range<br>(ft above msl) |
|--|--|-----------------------------|-----------------------------------|
| Qbt,<br>Tshirege<br>Member,<br>Bandelier Tuff<br>(Undivided) | No core recovered from this interval. At 48 ft bgs the rock became softer and the drilling rate increased.<br>: Qal/Qbt contact estimated at 47 ft bgs.  | 46–51                       | 6591.6–6586.6                     |
|  | Rhyolite tuff, identified from cuttings as no core recovered from this interval. Supplemental cuttings sample (from 50 to 55 ft bgs) contained rhyolite tuff, light brown (5YR 5/6), 30% pumice (up to 1.0 cm), very pale orange (10YR 8/2), fibrous; 5% phenocrysts (up to 2 mm), mostly quartz with some sanidine, phenocrysts larger in pumices; 1–2% lithic fragments (up to 5 mm), gray to reddish-brown; glassy ash matrix, nonwelded, streaks of orange staining, some devitrification. | 51–56                       | 6586.6–6581.6                     |
|  | Rhyolite tuff, identified from cuttings as no core recovered from this interval. Supplemental cuttings sample from (55 to 59.5 ft bgs) contains rhyolite tuff, light brown (5YR 6/4), 35% pumice (up to 1.2 cm), fibrous, partially devitrified but mostly glassy; 10% phenocrysts (up to 2 mm) of quartz with some sanidine, phenocrysts larger in pumices; 1–2% dark gray lithic fragments (up to 2 mm); 58% glassy ash matrix, glass shards evident, nonwelded, moist.                      | 56–61                       | 6581.6–6576.6                     |
|  | Only core recovered from this interval were a few dacite clasts plugging end of core barrel. Because of formation instability, the borehole was abandoned. Drilling and sampling continued at 63 ft bgs in a new drill hole nearby.  | 61–66                       | 6576.6–6571.6                     |
|  | Core recovered in this interval submitted for laboratory analysis prior to examination. Core interval from new hole location overlaps that of the first borehole.  | 63–66                       | 6574.6–6571.6                     |
|  | Rhyolite tuff, light pink.   | 66–71                       | 6571.6–6566.6                     |
|  | Rhyolite tuff, grayish-orange pink (5YR 7/2). 30% pumice (up to 1.5 cm), mostly sugary but with some fibrous texture; 10% phenocrysts (up to 2 mm), quartz and sanidine, < 1% lithic fragments (up to 5 mm), dark gray; 60% glassy ash matrix, glass shards evident, nonwelded, damp.  | 71–76                       | 6566.6–6561.6                     |
|  | Rhyolite tuff, grayish-orange pink (5YR 7/2). 35% fibrous pumice (up to 1.8 cm), sugary texture present, some alteration; 10% phenocrysts (up to 2 mm), quartz and sanidine, 1% lithic fragments (up to 5 mm), gray, 55% ash matrix, glassy shards evident, matrix partially devitrified, nonwelded, damp.   | 76–81                       | 6561.6–6556.6                     |
|  | Rhyolite tuff, grayish-orange pink (5YR 7/2). 35% fibrous pumice (up to 1.8 cm), sugary texture present, some alteration; 10% phenocrysts (up to 2 mm), quartz and sanidine, 1% lithic fragments (up to 5 mm), gray, 55% ash matrix, glassy shards evident, matrix partially devitrified, nonwelded, damp.   | 81–86                       | 6556.6–6551.6                     |
|  | Rhyolite tuff, grayish-orange pink (5YR 7/2). 25% fibrous pumice (up to 1.2 cm), some alteration evident, 12% phenocrysts (up to 2 mm), quartz and sanidine, < 1% lithic fragments (up to 5 mm), brown, 63% glassy ash matrix, glassy shards evident, nonwelded, damp.   | 86–91                       | 6551.6–6546.6                     |

| Geologic Unit  | Lithologic Description   | Sample Interval<br>(ft bgs) | Elevation Range<br>(ft above msl) |
|--|--|-----------------------------|-----------------------------------|
| Qbt,<br>Tshirege<br>Member,<br>Bandelier Tuff<br>(Undivided) | Rhyolite tuff, very pale orange (10YR 8/2). 50% pumice (up to 3.0 cm), some alteration evident; 5% phenocrysts (up to 3 mm), mostly quartz, some sanidine, <1% lithic fragments (up to 1 mm), gray to reddish-brown; 45% glassy ash matrix, glass shards evident, nonwelded, damp.   | 91–96                       | 6546.6–6541.6                     |
|  | Rhyolite tuff, grayish orange pink (5YR 7/2). 45% fibrous pumice (up to 3.0 cm); 7% phenocrysts (up to 2 mm), quartz and sanidine < 1% lithic fragments (up to 2 mm), gray; 48% glassy ash matrix, glass shards evident, nonwelded, damp.  | 96–101                      | 6541.6–6536.6                     |
|  | Rhyolite tuff, very pale orange (10YR 8/2). 55% fibrous pumice (up to 2.0 cm) some alteration evident; 7% phenocrysts (up to 3 mm), mostly quartz, some sanidine; <1% lithic fragments (up to 2 mm), mostly dark gray; 38% glassy ash matrix, glass shards evident, nonwelded, moist.  | 101–106                     | 6536.6–6531.6                     |
|  | Rhyolite tuff, very pale orange (10YR 8/2). 50% fibrous pumice (up to 4.0 cm) some alteration, 10% phenocrysts (up to 2 mm) of quartz and sanidine, 2–3% lithic fragments, gray, dacite (up to 2.0 cm); 38% glassy ash matrix, glass shards evident, nonwelded, damp.  | 106–111                     | 6531.6–6526.6                     |
|  | Rhyolite tuff, very pale orange (10YR 8/2). 40% fibrous pumice (up to 2.0 cm), some alteration evident; 10% phenocrysts (up to 3 mm), mostly quartz, some sanidine, <1% lithic fragments (up to 1.0 cm), gray; 50% glassy ash matrix, glass shards evident, nonwelded, damp.   | 111–116                     | 6526.6–6521.6                     |
|  | Rhyolite tuff, very pale orange (10YR 8/2). 40% fibrous pumice (up to 1.5 cm) some alteration evident; 7% phenocrysts (up to 3 mm) of quartz and sanidine <1% lithic fragments (up to 3 mm), mostly gray, some brown; 53% glassy ash matrix, glass shards evident, nonwelded, damp to moist.   | 116–121                     | 6521.6–6516.6                     |
|  | Rhyolite tuff, very pale orange (10YR 8/2). 50% fibrous pumice (up to 2.0 cm), some alteration evident; 5% phenocrysts (up to 2 mm) of quartz and sanidine, <1% lithic fragments (up to 2 mm), mostly gray, some black and red; 40% glassy ash matrix, glass shards evident, nonwelded, damp.  | 121–126                     | 6516.6–6511.6                     |
|  | Rhyolite tuff, very pale orange (10YR 8/2). 50% fibrous pumice (up to 3.0 cm) some alteration evident; 5% phenocrysts (up to 1 mm) of quartz and sanidine, <1% lithic fragments (up to 5 mm), gray, black, and light brown; 45% glassy ash matrix, glass shards evident, nonwelded, damp.  | 126–131                     | 6511.6–6506.6                     |
|  | Rhyolite tuff, very pale orange (10YR 8/2). 40% fibrous pumice (up to 2.0 cm) some alteration evident; 5% phenocrysts (up to 2 mm) of euhedral quartz and sanidine; <1% lithic fragments (up to 5 mm), gray, black, and red; 55% glassy ash matrix, abundant glass shards, nonwelded, damp with dark orange staining near 135 ft. No core recovery from 135 to 136 ft bgs. | 131–136                     | 6506.6–6501.6                     |

| Geologic Unit                           | Lithologic Description  | Sample Interval<br>(ft bgs) | Elevation Range<br>(ft above msl) |
|---|---|-----------------------------|-----------------------------------|
| Qct,<br>Cerro Toledo<br>Interval        | Rhyolite tuff, grayish-orange (10YR 7/4). 40% slightly fibrous, mostly devitrified pumice (up to 1.0 cm); 15% phenocrysts (up to 2 mm), anhedral to euhedral quartz and sanidine; 1-2% lithic fragments (up to 4 mm), gray, black, and red; 40% glassy ash matrix, glass shards evident, nonwelded, iron oxide staining present, damp.<br>Note: Qbt/Qct interval estimated at 138 ft bgs.   | 136–141                     | 6501.6–6496.6                     |
|   | Volcaniclastic sediments, sand (SW), moderate yellowish-brown (10YR 5/4), fine to medium-grained, subangular to rounded sand grains. 35% quartz, 35% sanidine, 25% pumice; 5% lithic fragments; granular, oxidized, moist.  | 141–146                     | 6496.6–6491.6                     |
|   | Volcaniclastic sediments, sand (SW) with gravel, moderate yellowish-brown (10YR 5/4) with light bluish-gray (5B 5/4) epiclastic pumice, subangular to subrounded clasts. 35% quartz; 35% sanidine; 25% pumice; 5% lithic fragments; granular, pumices have iron-oxide staining (limonite), trace of dacite gravel, moist. No core recovered from 150 to 151 ft bgs.   | 146–151                     | 6491.6–6486.6                     |
|   | No core recovered from this interval.   | 151–153.5                   | 6486.6–6484.1                     |
|   | No core recovered from this interval. Supplemental cuttings sample contains volcaniclastic sediments, gravel (GW) with sand, dacite gravel and cobbles, medium gray (N5); fine-grained sand, moderate yellowish-brown (10YR 5/4), crystals of sanidine, pyroxene, anhedral quartz, and plagioclase present.   | 153.5–156                   | 6484.1–6481.6                     |
|   | No core recovered from this interval.   | 156–161                     | 6481.6–6476.6                     |
|   | No core recovered. Lithologic description from cuttings. Supplemental cuttings sample contains volcaniclastic sediments, gravel (GW) with sand, dacite sand and gravel, medium gray (N5), subrounded clasts (up to 5.0 cm), fine matrix; +10F: 80% anhedral quartz and sanidine crystals; 10% pumice; 5–10% volcanic lithic fragments, iron oxide staining (limonite). +35F: subangular to subrounded grains. No core recovered from 162 to 164 ft bgs. | 161–164                     | 6476.6–6473.6                     |
|   | No core recovered from 164–168 ft bgs..   | 164–168                     | 6473.6–6469.6                     |
|   | No core recovered from this interval except material plugging end of core barrel. Lithologic description from cuttings. Supplemental cuttings sample contains volcaniclastic sediments, gravel (GW) with sand, moderate brown (5YR 4/4) to medium-dark gray (N4), angular to rounded clasts, mostly of porphyritic dacite or latite with anhedral phenocrysts of plagioclase, sanidine, hornblende in an aphanitic groundmass; unconsolidated, moist.   | 168–170.5                   | 6469.6–6467.1                     |
|   | No core recovered from this interval.<br>Note: Qct/Qbo contact estimated at 174 ft bgs.   | 170.5–174                   | 6467.1–6463.6                     |
| Qbo,<br>Otowi Member,<br>Bandelier Tuff | Core recovered in this interval consisted of material plugging end of core barrel. Volcaniclastic sediment, silty sand (SM) and tuff, grayish-orange (10YR 7/4), tuffaceous, ash-rich, glassy, nonwelded, possible weak calcite cementation, moist to wet.  | 174–176                     | 6463.6–6461.6                     |

| Geologic Unit                           | Lithologic Description   | Sample Interval<br>(ft bgs) | Elevation Range<br>(ft above msl) |
|---|--|-----------------------------|-----------------------------------|
| Qbo,<br>Otowi Member,<br>Bandelier Tuff | No core recovered from this interval. At approximately 181 ft bgs drilling became easier, suggesting softer rock formation.  | 176–181                     | 6461.6–6456.6                     |
|   | No core recovered from this interval except material plugging end of core barrel. Lithologic description from cuttings. Supplemental cuttings sample consisted of rhyolite tuff, very pale orange (10YR 8/2), lithic-rich, nonwelded. +10F: 30–40% dark colored lithic fragments (up to 2.0 cm), mostly dacite and andesite 10–20% quartz and sanidine crystals (up to 3 mm); 10% pumice fragments; 20% ash. | 181–186                     | 6456.6–6451.6                     |
|   | No core recovered from this interval.  | 186–201                     | 6451.6–6436.6                     |
|   | Rhyolite tuff, pale yellowish-brown (10YR 6/2), poorly welded. 60% fibrous pumices (up to 4 mm); 15% quartz and sanidine phenocrysts (up to 4 mm); < 5% lithic fragments (up to 3 mm); 20% glassy ash matrix, glass shards evident. No core recovered from 201.5 to 206.0 ft bgs.  | 201–206                     | 6436.6–6431.6                     |
|   | Rhyolite tuff, pale yellowish-brown (10YR 6/2), poorly welded. 30% pumice (up to 2.0 cm), some fibrous; 10% quartz and sanidine phenocrysts (up to 5 mm); 20% lithic fragments (up to 1.5 cm), mostly dacite with some mafic phenocrysts; 50% glassy ash matrix. No core recovered from 208.0 to 211.0 ft bgs.   | 206–211                     | 6431.6–6426.6                     |
|   | Rhyolite tuff, pale yellowish-brown (10YR 6/2), poorly welded. 30% pumice (up to 2.0 cm), some fibrous; 10% quartz and sanidine phenocrysts (up to 5 mm); 20% lithic fragments (up to 1.5 cm), mostly dacite with some mafics; 50% glassy ash matrix. No core recovered from 211.7 to 216.0 ft bgs.  | 211–216                     | 6426.6–6421.6                     |
|   | Rhyolite tuff, pale yellowish-brown (10YR 6/2), poorly welded. 30% pumice, some fibrous (up to 2.0 cm); 10% quartz and sanidine phenocrysts (up to 5 mm); 20% lithic fragments, mostly dacite with some mafic phenocrysts (up to 1.5 cm); 50% glassy ash matrix. No core recovered between 216.7–221.0 ft bgs.   | 216–221                     | 6421.6–6416.6                     |
|   | Very poor core recovery in this interval. Tan-colored lithic-rich tuff. No core recovered from 221.1 to 224.5 ft bgs.  | 221–224.5                   | 6416.6–6413.1                     |
|   | Rhyolite tuff, pale yellowish-brown (10YR 6/2), lithic-rich, poorly welded. 40% dark volcanic lithic fragments (up to 1.5 cm), mostly dacite and andesite; 50% glassy ash matrix, with quartz, sanidine and pumice fragments (up to 4 mm), some fibrous, some devitrified. No core recovered from 224.7 to 226.0 ft bgs.   | 224.5–226                   | 6413.1–6411.6                     |
|   | No core recovery from this interval.   | 226–231                     | 6411.6–6406.6                     |
|   | Rhyolite tuff, grayish-orange pink (5YR 7/2), lithic-rich, poorly welded. 30% fibrous pumice (up to 1.5 cm); 10% quartz and sanidine phenocrysts (up to 4 mm); 15% dark lithic fragments (up to 1.6 cm) of dacite and andesite. 45% glassy ash matrix, glass shards evident, perlitic texture. No core recovered from 234.5 to 236.0 ft bgs.   | 231–236                     | 6406.6–6401.6                     |

| Geologic Unit                           | Lithologic Description  | Sample Interval<br>(ft bgs) | Elevation Range<br>(ft above msl) |
|---|---|-----------------------------|-----------------------------------|
| Qbo,<br>Otowi Member,<br>Bandelier Tuff | Rhyolite tuff, grayish-orange pink (5YR 7/2), lithic-rich, poorly welded. 30% fibrous pumice (up to 1.5 cm); 10 % quartz and sanidine phenocrysts (up to 4 mm); 15% dark lithic fragments (up to 1.6 cm), dacite and andesite. 45% glassy ash matrix, glass shards evident, perlitic texture. No core recovered from 239.0 to 241.0 ft bgs.   | 236–241                     | 6401.6–6396.6                     |
|   | No core recovered from this interval.   | 241–242                     | 6396.6–6395.6                     |
|   | Rhyolite tuff, pale yellowish-brown (10YR 4/2), nonwelded. 25% pumice (up to 1.5 cm); 5% quartz and sanidine phenocrysts (up to 2 mm); 15% lithic fragments (up to 3 mm), red to black; 55% glassy ash matrix, glass shards evident. No core recovered between 243.0–244.0 ft bgs.  | 242–244                     | 6395.6–6393.6                     |
|   | No core recovered from this interval.   | 244–251                     | 6393.6–6386.6                     |
|   | Rhyolite tuff, pale yellowish-brown (10YR 6/2). 40% fibrous pumice (up to 1.0 cm), some alteration evident; 5% anhedral quartz and sanidine phenocrysts (up to 2 mm); 10% lithic fragments (up to 3 mm) red, orange, gray, and black, mostly dacite; 45% glassy ash matrix, glass shards evident.   | 251–253.5                   | 6386.6–6384.1                     |
|   | No core recovered from 253.6 to 261.0 ft bgs.   | 253.5–261                   | 6384.1–6376.6                     |
|   | Rhyolite tuff, pale yellowish-brown (10YR 6/2). 35% fibrous pumice (up to 1.0 cm), some devitrified; 5% subhedral to anhedral quartz and sanidine phenocrysts (up to 2 mm); 5% lithic fragments (up to 2 mm), red, gray, and black; 55% glassy ash matrix, glass shards evident, damp. No core recovered from 265.0 to 266.0 ft bgs.  | 261–266                     | 6376.6–6371.6                     |
|   | Rhyolite tuff, pale yellowish-brown (10YR 6/2). 35% fibrous pumice (up to 1.0 cm) some devitrified; 5% subhedral to anhedral quartz and sanidine phenocrysts (up to 2 mm); 5% lithic fragments (up to 2 mm), red, gray, and black; 55% glassy ash matrix, glass shards evident, damp. No core recovered from 270.5 to 271.0 ft bgs.   | 266–271                     | 6371.6–6366.6                     |
|   | No core recovered from this interval except material plugging end of core barrel. Rhyolite tuff, pale yellowish-brown (10YR 6/2). 20% glassy pumice (up to 1.0 cm) some devitrified; 5% subhedral to anhedral quartz and sanidine phenocrysts (up to 2 mm); 25% lithic fragments, medium gray (N5) rounded dacite cobbles and gravel with oxidation present in voids and vugs; 50% glassy ash matrix, glass shards evident. | 271–276                     | 6366.6–6361.6                     |
|   | Rhyolitic tephra, moderate yellowish-brown (10YR 5/4). 75% mostly fibrous pumice (up to 1.0 cm), some devitrified; 5% quartz and sanidine phenocrysts (up to 2 mm); 5% lithic fragments (up to 3 mm); 15% ash and glassy shards; damp. Note: Qbo/Qbog contact estimated at 277 ft bgs.  | 276–281                     | 6361.6–6356.6                     |
| Qbog,<br>Guaje Pumice<br>Bed            | Tephra deposit, moderate yellowish-brown (10YR 5/4). 75% mostly fibrous pumice lapilli (up to 1.0 cm) with some alteration; 5% quartz and sanidine phenocrysts (up to 2 mm); 5% lithic fragments (up to 3 mm); 15% ash and glassy shards; damp. No core recovered from 285.3 to 286.0 ft bgs.   | 281–286                     | 6356.6–6351.6                     |

| Geologic Unit                   | Lithologic Description   | Sample Interval<br>(ft bgs) | Elevation Range<br>(ft above msl) |
|---------------------------------|--|-----------------------------|-----------------------------------|
| Tb4,<br>Cerro del Rio<br>Basalt | Volcaniclastic sediments, silty sand (SM) with gravel, moderate brown (5YR 4/4). 60% subrounded fine-grained sand; 25% subangular scoriaceous basalt gravel, 15% silt; moist, possible paleosol developed on top of basalt. No core recovered between 286.7–291.0 ft bgs.<br>Note: Qbog/Tb4 contact estimated at 287 ft bgs.   | 286–291                     | 6351.6–6346.6                     |
|                                 | No core recovered from 291–301.  | 291–301                     | 6346.6–6336.6                     |
|                                 | Only core recovered from this interval is vesicular basalt material plugging end of core barrel.   | 301–302                     | 6938.6–6335.6                     |
|                                 | Basalt. No core recovered from 303.0 to 306.0 ft bgs.  | 302–306                     | 6335.6–6331.6                     |
|                                 | Basalt. No core recovered from 306.5 to 308.0 ft bgs.  | 306–308                     | 6331.6–6329.6                     |
|                                 | Basalt. No core recovered from 310.3 to 311.0 ft bgs.  | 308–311                     | 6329.6–6326.6                     |
|                                 | Basalt. No core recovered from 311.9 to 312.0 ft bgs.  | 311–312                     | 6326.6–6325.6                     |
|                                 | Basalt. No core recovered from 312.2 to 314.0 ft bgs.  | 312–314                     | 6325.6–6323.6                     |
|                                 | Basalt, black, vesicular. No core recovered from 314.7 to 316.0 ft bgs.  | 314–316                     | 6323.6–6321.6                     |
|                                 | No core recovered from this interval. Possible void(s) or cavity in basalt.<br>Note: End of core sampling. The remainder of the lithological descriptions (318 – 923 ft bgs) are from cuttings samples.  | 316–318                     | 6321.6–6319.6                     |
|                                 | Basalt, medium-dark gray (N4), porphyritic with aphanitic groundmass, few vesicles. +10F: phenocrysts of yellowish-brown, euhedral pyroxene, subhedral plagioclase. Pervasive clay alteration of groundmass, rare clay nodules, reddish oxidation pits, clay and iron oxide lining of fracture and vesicle surfaces; rare pumice fragments.  | 318–333                     | 6319.6–6304.6                     |
|                                 | Basalt, medium-dark gray (N4), vesicular, slightly porphyritic with aphanitic to fine-grained groundmass. +10F: phenocrysts (5–7%) of yellowish-brown to transparent euhedral pyroxene and green olivine; pervasive alteration of groundmass, rare reddish oxidation pits; 15% clear to white quartz; rare pumice fragments.   | 333–343                     | 6304.6–6294.6                     |
|                                 | Basalt, dark gray (N3), massive, porphyritic with aphanitic to fine-grained groundmass. +10F: phenocrysts (up to 5 mm) of anhedral olivine and subhedral plagioclase; slightly oxidized, local iron-oxide and clay coating fractures; groundmass pervasively altered.  | 343–348                     | 6294.6–6289.6                     |
|                                 | Basalt, medium gray (N5), slightly porphyritic with aphanitic to fine-grained groundmass, massive to slightly vesicular, angular chips. +10F: phenocrysts (3–5%) of plagioclase, and green to amber olivines that are unaltered to slightly oxidized; groundmass strongly altered.   | 348–363                     | 6289.6–6274.6                     |
|                                 | Basalt, medium-dark gray (N4) to brownish-gray (5YR 4/1), massive to scoriaceous, slightly porphyritic with aphanitic groundmass. +10F: basalt contains phenocrysts of altered olivine, plagioclase and hornblende; groundmass altered; white clay coating fractures and filling vesicles, fine acicular crystals of possible zeolite(?) evident, moderate amounts of iron oxide in vesicles; 3–5% altered pumice. | 363–368                     | 6274.6–6269.6                     |

| Geologic Unit                    | Lithologic Description   | Sample Interval<br>(ft bgs) | Elevation Range<br>(ft above msl) |
|----------------------------------|--|-----------------------------|-----------------------------------|
| Tb 4,<br>Cerro del Rio<br>Basalt | Basalt, dark gray (N3), porphyritic with aphanitic groundmass, abundant vesicles to scoriaceous texture. Phenocrysts (5–7%, up to 2mm) of highly altered olivine; 2–3% generally unaltered plagioclase phenocrysts (up to 3 mm), rare altered pumice; white clay, iron oxide, possible zeolite (?) and calcite coating fractures and filling vesicles. Pervasive alteration of the groundmass. | 368–383                     | 6269.6–6254.6                     |
|                                  | Basalt, medium-dark gray (N4), porphyritic with aphanitic groundmass, slightly vesicular to massive. +10F: phenocrysts (2–3% up to 2mm) of unaltered to strongly oxidized olivine; strong alteration of groundmass.  | 383–388                     | 6254.6–6249.6                     |
|                                  | No cuttings returned and no samples collected from this interval.  | 388–393                     | 6249.6–6244.6                     |
|                                  | Basalt, medium-light gray (N6), porphyritic with aphanitic groundmass, vesicular to massive. +10F: phenocrysts (up to 2 mm) of oxidized olivine, pervasive alteration of the groundmass, limonite in fractures and vesicles; 1–2% subrounded dacite lithics; minor altered pumice. WR sample is clayey.  | 393–403                     | 6244.6–6234.6                     |
|                                  | Basalt, medium-dark gray (N4), porphyritic with aphanitic groundmass, massive to partly vesicular. +10 F: phenocrysts (up to 2 mm) of unaltered, pale green olivine and phenocrysts (up to 3 mm) of plagioclase. Minor scoria with strong iron-oxide staining.   | 403–413                     | 6234.6–6224.6                     |
|                                  | Basalt, medium gray (N5), mostly scoria with some massive basalt. WR sample contains white clay chips. +10F: strongly oxidized scoria, olivine phenocrysts completely replaced by iron oxide; vesicles iron-oxide stained and/or lined with white clay; groundmass strongly altered.   | 413–428                     | 6224.6–6209.6                     |
|                                  | Basalt, medium-light gray (N6), porphyritic with aphanitic groundmass, mostly massive, locally vesicular. WR sample contains moderate to abundant clay-coated chips. +10F: 2-3% unaltered, pale green olivine phenocrysts (up to 1 mm); pervasive alteration of groundmass; local iron-oxide coating on vesicles.  | 428–448                     | 6209.6–6189.6                     |
|                                  | Basalt, medium-dark gray (N4), massive, slightly porphyritic with aphanitic to microcrystalline groundmass. WR sample contains moderate amounts of clay. +10F: phenocrysts (up to 1 mm) of unaltered, pale green olivine and phenocrysts of plagioclase (up to 2 mm); pervasive alteration of the groundmass.  | 448–458                     | 6189.6–6179.6                     |
|                                  | Basalt, medium gray (N5), vesicular, porphyritic with aphanitic to microcrystalline groundmass. WR sample contains chips coated with moderate amounts of white clay and silt. +10F: unaltered olivine phenocrysts (3–5%, up to 3 mm) are pale green; vesicles commonly coated with yellowish-brown limonite; pervasive alteration of the groundmass.   | 458–473                     | 6179.6–6164.6                     |

| Geologic Unit                    | Lithologic Description  | Sample Interval<br>(ft bgs) | Elevation Range<br>(ft above msl) |
|----------------------------------|---|-----------------------------|-----------------------------------|
| Tb 4,<br>Cerro del Rio<br>Basalt | Basalt, medium gray (N5), porphyritic with aphanitic to microcrystalline groundmass, massive to vesicular. WR sample contains chips coated with moderate amounts of white clay. +10F: phenocrysts (3–6%, up to 3mm) of green to brown, euhedral olivine; plagioclase phenocrysts (up to 2 mm); moderate to pervasive alteration of the groundmass.  | 473–488                     | 6164.6–6149.6                     |
|                                  | Basalt, medium gray (N5), porphyritic with aphanitic groundmass, massive. +10F: olivine phenocrysts (2–3%, up to 2mm) mostly unaltered, green to brown; moderate to pervasive alteration of the groundmass.   | 488–493                     | 6149.6–6144.6                     |
|                                  | Basalt, medium gray (N5), massive porphyritic with aphanitic groundmass. WR sample contains chips coated with moderate amounts of white clay. +10F: dark olivine phenocrysts (2–4%, up to 1mm) that have been oxidized or totally replaced by iddingsite; moderate to pervasive alteration of the groundmass; 5–7% reddish brown oxidized scoria.   | 493–503                     | 6144.6–6134.6                     |
|                                  | Basalt, medium gray (N5) to brick red (5R 4/6), approximately equal portions of gray massive basalt and red scoriaceous basalt. Massive basalt is porphyritic with aphanitic groundmass, olivine-rich. +10F: massive basalt contains 3–5% olivine phenocrysts (up to 2 mm) partly to wholly replaced by iddingsite; groundmass pervasively altered; scoriaceous basalt is limonite-stained; gypsum crystals (up to 5 mm) evident. +35F (i.e., plus No. 35 size sieved sample fraction) contains 60–80% oxidized scoria. | 503–513                     | 6134.6–6124.6                     |
|                                  | Basalt, medium gray (N5), porphyritic with aphanitic groundmass, mostly massive with few vesicles, trace of scoria. +10F: 3–5% coarse brown olivine phenocrysts partly to wholly replaced by iddingsite, pervasive alteration of the groundmass. 10–15% reddish scoria.   | 513–528                     | 6124.6–6109.6                     |
|                                  | Basalt, medium gray (N5), massive, porphyritic with aphanitic groundmass. +10F: olivine phenocrysts (2–4%, up to 2 mm), green to brown, unaltered to partly replaced by iddingsite, some plagioclase phenocrysts; groundmass bleached and pervasively altered; 5–10% brick-red scoria.  | 528–548                     | 6109.6–6089.6                     |
|                                  | Basalt, medium gray (N5), porphyritic with aphanitic groundmass, massive. +10F: platy chips of basalt, phenocrysts (up to 3 mm) of olivine (2–4%) that are partly to entirely replaced by iddingsite, phenocrysts of plagioclase; groundmass strongly altered.  | 548–558                     | 6089.6–6079.6                     |
|                                  | Basalt, medium-dark gray (N4), massive to scoriaceous, porphyritic with aphanitic groundmass, olivine-rich. +10F: equal proportions of gray massive and pinkish scoriaceous basalt chips; phenocrysts (up to 1mm) of olivine (2–3% by volume) that are mostly replaced by iddingsite and commonly cumulo-phyrlic; groundmass strongly altered; scoriaceous basalt generally iron-oxide stained.   | 558–573                     | 6079.6–6064.6                     |
|                                  | Basalt, medium-dark gray (N4), massive, porphyritic with aphanitic groundmass. +10F: phenocrysts (2–4% by volume) of anhedral olivine (up to 2 mm) that are mostly replaced by iddingsite; pervasive alteration of groundmass.  | 573–588                     | 6064.6–6049.6                     |

| Geologic Unit                    | Lithologic Description   | Sample Interval<br>(ft bgs) | Elevation Range<br>(ft above msl) |
|----------------------------------|--|-----------------------------|-----------------------------------|
| Tb 4,<br>Cerro del Rio<br>Basalt | Basalt, medium-dark gray (N4), scoriaceous and massive, porphyritic with aphanitic groundmass. +10F: mostly gray massive basalt and lesser oxidized scoria; phenocrysts (2-4%, up to 2mm) anhedral olivine that are mostly replaced by iddingsite; pervasive alteration of groundmass; vesicular basalt is iron-oxide stained; vesicles commonly lined with yellow to tan clay; scoria is dominant between 593–598 ft.   | 588–598                     | 6049.6–6039.6                     |
|                                  | Basalt, medium-dark gray (N4), scoriaceous, porphyritic with aphanitic groundmass. WR/+10F: predominantly scoria, olivine phenocrysts (up to 2 mm), replaced by iddingsite and pervasively stained by reddish iron oxide; fractured surfaces and vesicles commonly coated with yellow clay; some limonitic siltstone; rare round nodules of yellow clay.   | 598–613                     | 6039.6–6024.6                     |
|                                  | Basalt, medium-light gray (N6), massive and scoriaceous, porphyritic with aphanitic groundmass. +10F: mixture of light gray massive basalt and pale reddish scoria; light gray massive basalt has olivine phenocrysts (up to 1 mm) that are generally unaltered; intense clay alteration of groundmass; fine-grained salt and pepper texture from remnant fine-grained magnetite crystals. Scoriaceous basalt is reddish, iron-oxide stained; yellowish clay coating fractures and vesicles; groundmass bleached.  | 613–628                     | 6024.6–6009.6                     |
|                                  | Basalt, medium-light gray (N6), mostly massive, porphyritic with very fine-grained crystalline groundmass. +10F: olivine phenocrysts (3–5%, up to 1 mm) are pale green, unaltered to slightly oxidized; pervasively altered groundmass is bleached; 1% white clay nodules present; 5–15% limonite-stained, fine-grained volcanic sandstone clasts; 10% reddish scoria at 638–643 ft.   | 628–643                     | 6009.6–5994.6                     |
|                                  | Basalt, medium-light gray (N6), massive, porphyritic with very fine-grained crystalline groundmass. +10F: olivine phenocrysts (up to 1 mm) are pale green, unaltered to slightly oxidized; pervasively altered groundmass; 1% white clay nodules; 25% red scoria; 20–25% fragments of limonite-cemented, fine-grained volcanic sandstone clasts. +35F: 55–60% limonite-cemented fine-grained sandstone clasts.   | 643–648                     | 5994.6–5989.6                     |
|                                  | Basalt, varicolored, medium gray (N5) to pale red (5R 6/6), mixture of gray massive basalt and reddish scoria, fine-grained crystalline groundmass. +10F: 20–40% gray massive basalt contains pale green olivine phenocrysts (up to 1 mm), unaltered to slightly oxidized; pervasively altered groundmass; 50 – 80% reddish basalt scoria ranges from unaltered to some clay alteration present, orange to reddish-brown iron-oxide staining; vesicles commonly lined with white clay; 10–20% rounded fragments of orange to red, fine-grained volcanic sandstone. +35 F: 80–90% orange to red, fine-grained volcanic sandstone. | 648–658                     | 5989.6–5979.6                     |
|                                  | Basalt/volcaniclastic sediments, varicolored, reddish-brown (10R 6/6) to medium dark gray (N4). +10F: 30–50% orange to tan, fine-grained volcanic sandstone, grains of quartz, feldspar, and mafic lithic fragments, limonite- and clay-cemented; 10–30% black scoriaceous basalt; 10–20% gray, oxidized, massive basalt with white clay coating on chips.   | 658–668                     | 5979.6–5969.6                     |

| Geologic Unit                   | Lithologic Description   | Sample Interval<br>(ft bgs) | Elevation Range<br>(ft above msl) |
|---------------------------------|--|-----------------------------|-----------------------------------|
| Tb4,<br>Cerro del Rio<br>Basalt | Basalt/volcaniclastic sediments, varicolored, reddish-brown (10R 6/6) to medium dark gray (N4). +10F: 35–45% orange-brown to tan, fine-grained volcanic sandstone clasts, limonite- and clay-cemented; 50–60% black, aphanitic, angular scoriaceous basalt chips, vesicles commonly lined with whitish clay; 5–7% subrounded siliceous volcanic clasts (dacite). | 668–678                     | 5969.6–5959.6                     |
|                                 | Basalt/volcaniclastic sediments, grayish-black (N2) to light orange-tan (5YR 8/4). +10F: 70–80% angular black scoriaceous basalt chips, aphanitic, minor whitish clay lining vesicles; 10–20% subrounded to rounded orange-tan, fine-grained volcanic sandstone chips.   | 678–688                     | 5959.6–5949.6                     |
|                                 | Basalt, varicolored, grayish-black (N2) to pale tan (10YR 8/2). +10F: 80–90% angular black scoriaceous basalt chips, aphanitic, abundant white amygdaloidal clay; 10–15% pale tan clay; 2–3% subrounded volcanic sandstone chips.  | 688–698                     | 5949.6–5939.6                     |
|                                 | Basalt, grayish-black (N2), scoriaceous, slightly porphyritic, aphanitic groundmass. +10F: 80–90% black scoriaceous basalt, pale tan clay lining vesicles; 10–15% angular pale tan clay fragments; 5–7% volcanic sandstone.  | 698–708                     | 5939.6–5929.6                     |
|                                 | Basalt, medium-dark gray (N4), aphyric, aphanitic groundmass, slightly vesicular. +10F: mixed dark gray scoriaceous basalt and light gray massive basalt; massive basalt has moderate to strongly altered groundmass, trace of pyroxene and olivine phenocrysts; 3–7% pale tan clay chips; 1–3% fine-grained volcanic sandstone.                                 | 708–718                     | 5929.6–5919.6                     |
|                                 | Basalt, medium-dark gray (N4), slightly porphyritic with aphanitic groundmass. +10F: 85–90% massive to vesicular basalt, 1–2% unaltered pale green olivine phenocrysts (up to 1 mm), partially altered groundmass; 10–15% pale tan clay chips.   | 718–728                     | 5919.6–5909.6                     |
|                                 | Basalt, medium-dark gray (N4), aphyric, aphanitic groundmass +10F: 90% massive basalt, partially altered groundmass; 10% subangular pale tan clay chips.   | 728–738                     | 5909.6–5899.6                     |
|                                 | No cuttings returned and no samples collected in this interval.  | 738–743                     | 5899.6–5894.6                     |
|                                 | Basalt, medium-dark gray (N4), aphyric, aphanitic groundmass. +10F: 90–95% massive to slightly vesicular basalt, partially altered groundmass, pale tan clay lining some vesicles; 5–10% subangular pale tan clay chips.   | 743–758                     | 5894.6–5879.6                     |
|                                 | Basalt, varicolored, medium-dark gray (N4) to pale tan (10YR 8/2), aphyric, aphanitic groundmass, slightly vesicular. +10F: 85–90% basalt chips, partially altered groundmass; 10–15% pale tan clay chips.   | 758–773                     | 5879.6–5864.6                     |
|                                 | Basalt, varicolored, medium-dark gray (N4) to pale tan (10YR 8/2), aphyric, aphanitic groundmass, slightly vesicular. +10F: 85–90% basalt chips, partially altered groundmass; 10–15% pale tan clay chips.   | 773–788                     | 5864.6–5849.6                     |

| Geologic Unit                        | Lithologic Description   | Sample Interval<br>(ft bgs) | Elevation Range<br>(ft above msl) |
|--------------------------------------|--|-----------------------------|-----------------------------------|
| Tb4,<br>Cerro del Rio<br>Basalt      | Basalt, varicolored, medium-dark gray (N4) to pale tan (10YR 8/2), aphyric, aphanitic groundmass, partly vesicular to scoriaceous. +10F: 90–95% basalt chips, light tan clay coating most chips and lining vesicles; 10–15% light tan clay nodules.  | 788–798                     | 5849.6–5839.6                     |
|                                      | Basalt, varicolored, medium-dark gray (N4) to pale tan (10YR 8/2), slightly porphyritic with aphanitic groundmass, scoriaceous. +10F: 90–95% scoria, trace black opaque olivine phenocrysts (up to 2 mm), rare iddingsite replacement, rare plagioclase, abundant light tan amygdaloidal clay; 5–10% light tan clay nodules.   | 798–808                     | 5839.6–5829.6                     |
|                                      | Basalt, medium-light gray (N6) slightly porphyritic with aphanitic groundmass, massive, abrupt change in color and alteration at 808 ft. +10F: platy chips of massive basalt with 5–10% scoria, trace unaltered pale green olivine phenocrysts (up to 1 mm), groundmass pervasively altered and moderately bleached, chips commonly coated with clay.  | 808–823                     | 5829.6–5814.6                     |
|                                      | Basalt, medium-light gray (N6) slightly porphyritic with aphanitic groundmass, massive. +10F: monolithic basalt, trace unaltered pale green olivine phenocrysts (up to 1 mm), groundmass pervasively altered and bleached, chips have dusty white appearance.  | 823–838                     | 5814.6–5799.6                     |
|                                      | Basalt, medium-light gray (N6) slightly porphyritic with aphanitic groundmass, massive. WR/+10F: monolithic basalt, trace unaltered pale green olivine (up to 1 mm), groundmass partially altered and bleached.  | 838–858                     | 5799.6–5779.6                     |
|                                      | Basalt, medium-dark gray (N4), slightly porphyritic with aphanitic groundmass, massive. WR/+10F: basalt contains minor unaltered pale green olivine phenocrysts (up to 1 mm), groundmass pervasively altered and bleached.   | 858–863                     | 5779.6–5774.6                     |
| Tb4,<br>Interbedded<br>River Gravels | Basalt/clastic sediments, varicolored, medium-dark gray (N4) to orange-pink (10R 7/4). +10F: 85–90% angular basalt chips, slightly porphyritic with aphanitic groundmass, trace olivine phenocrysts (up to 1 mm), groundmass partially altered; 10–15% sedimentary clasts of varying lithologies, fragments of quartzite, granitic rocks, potassium feldspar, and very fine-grained sandstone and/or siltstone, clasts mostly broken with some rounded edges. River gravels interpreted to occur from 863 to 870 ft bgs. | 863–873                     | 5774.6–5764.6                     |
|                                      | Basalt/clastic sediments, varicolored, medium-dark gray (N4) to orange-pink (10R 7/4). +10F: 80–85% basalt, massive to vesicular, aphyric, aphanitic groundmass variably altered; 15–20% coarse gravel clasts of varying lithologies, including fragments of very fine-grained sandstone and/or siltstone, quartzite, orthoclase, rhyolite, and granitic rock, clasts exhibit subrounded to rounded surfaces; trace of silty clay.   | 873–883                     | 5764.6–5754.6                     |

| Geologic Unit                        | Lithologic Description  | Sample Interval<br>(ft bgs) | Elevation Range<br>(ft above msl) |
|--------------------------------------|---|-----------------------------|-----------------------------------|
| Tb4,<br>Interbedded<br>River Gravels | Basalt/clastic sediments, varicolored, medium-dark gray (N4) to orange-pink (10R 7/4). +10F: 80–85% angular basalt, aphyric, aphanitic, groundmass partially altered; 15–20% broken clasts of varying lithologies, fragments of quartzite, potassium feldspar, granitic rock, and siltstone, subrounded surfaces indicate probably coarse gravel clasts; some silty clay.   | 883–888                     | 5754.6–5749.6                     |
|                                      | No cuttings returned and no samples collected in this interval.   | 888–894                     | 5749.6–5743.6                     |
|                                      | Volcaniclastic sediments, sand (SP), pale yellowish-brown. WR sample contains fine-grained sand, subangular grains of quartz, feldspar, and volcanic lithics, probable tuffaceous source; 2–3% silt and/or clay.  | 894–895                     | 5743.6–5742.6                     |
|                                      | No cuttings returned and no samples collected in this interval.   | 895–908                     | 5742.6–5729.6                     |
|                                      | Basalt/clastic sediments, varicolored, medium-dark gray (N4) to pale orange-tan (10YR 8/2). +10F: 60–70% angular basalt, slightly porphyritic, aphanitic groundmass, olivine phenocrysts (up to 1 mm), groundmass unaltered to very slightly altered; 30–40% broken clasts of varying lithologies, fragments mostly of quartzite and granitic rock, some very fine-grained sandstone and siltstone, subrounded to rounded surfaces indicate probable gravel clasts. | 908–913                     | 5729.6–5724.6                     |
|                                      | Basalt/clastic sediments, varicolored, medium-dark gray (N4) to pale orange-tan (10YR 8/2). +10F: 50–60% angular basalt, slightly porphyritic, aphanitic groundmass, olivine phenocrysts (up to 1 mm), groundmass unaltered to slightly altered; 40–50% rounded clasts of varying lithologies (up to 1 cm), clasts of very fine-grained sandstone and siltstone, quartzite, potassium feldspar, and granitic rock.  | 913–915.5                   | 5724.6–5722.1                     |
|                                      | No cuttings returned and no samples collected in this interval.   | 915.5–923                   | 5722.1–5714.6                     |
| Tpf,<br>Puye Formation               | No cuttings returned and no samples collected in this interval. Loss of drilling fluid circulation inhibited sample collection.<br>Note: Tb4/Tpf contact estimated at 923 ft bgs as interpreted from geophysical logs.  | 923–1008                    | 5714.6–5629.6                     |
|                                      | R-32 BOREHOLE COMPLETED AT 1008 FT BGS TOTAL DEPTH.   |                             |                                   |

## Notes:

- American Society for Testing Materials (ASTM) standards (D 2488-90: Standard Practice and Identification of Soils [Visual-Manual Procedure]) were used to describe the texture of drill chip samples for sedimentary rocks such as alluvium and the Puye Formation. ASTM method D 2488-90 incorporates the Unified Soil Classification System (USCS) as a standard for field examination and description of soils. The following standard USCS symbols were used in the R-32 lithologic log:  
SW = Well-graded sand      SM = Silty gravel      CH = Clay, high plasticity  
GW = Well-graded gravel      GM = Silty gravel  
GP = Poorly graded gravel      GC = Silt
- Cuttings were collected at nominal 5-ft intervals and divided into three sample splits: (1) unsieved, or whole rock (WR) sample; (2) +10F sieved fraction (No. 10 sieve equivalent to 2.0 mm); and (3) +35F sieved fraction (No. 35 sieve equivalent to 0.50 mm).
- The term *percent*, as used in the above descriptions, refers to percent by volume for a given sample component.
- Color designations such as hue, value, and chroma (e.g., 5YR 5/2) are from the Geological Society of America's Rock Color Chart.

## **Appendix D**

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*LANL Borehole Video Log  
(CD attached to inside back cover)*

## **Appendix E**

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*Schlumberger Geophysical Report/Montage  
(CD attached to inside back cover)*

## **Appendix F**

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*Westbay™ Multi-Level Sampling Diagram  
(CD attached to inside back cover)*

# **Appendix G**

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*Waste Characterization Data*



*Risk Reduction & Environmental Stewardship Division*  
*Water Quality & Hydrology Group (RRES-WQH)*  
PO Box 1663, MS K497  
Los Alamos, New Mexico 87545  
(505) 667-7969/Fax: (505) 665-9344

Date: October 8, 2002  
Refer to: RRES-WQH: 02-372

Mr. John Young  
Hazardous Materials Bureau  
New Mexico Environment Department  
P.O. Box 26110  
Santa Fe, New Mexico 87502

Mr. Curt Frischkorn  
Ground Water Quality Bureau  
New Mexico Environment Department  
P.O. Box 26110  
Santa Fe, New Mexico 87502

**SUBJECT: NOTICE OF INTENT TO DISCHARGE, HYDROGEOLOGIC WORKPLAN  
WELL R-32**

Dear Mr. Young and Mr. Frischkorn:

On October 4, 2002, your agency concurred with Los Alamos National Laboratory's proposal to land apply approximately 100,000 gallons of ground water produced during the development of Hydrogeologic Workplan Well R-32 (personal communication, Mr. Roy Bohn, Los Alamos National Laboratory, and Mr. John Young, New Mexico Environment Department, October 4, 2002). The Laboratory's proposal to discharge development water from Workplan Well R-32 was made in accordance with the requirements of the Hydrogeologic Workplan Notice of Intent (NOI) submitted to your agency on August 2, 2001, and subsequently revised on July 16, 2002. Under the Hydrogeologic Workplan NOI, when development water produced from a Hydrogeologic Workplan Well exceeds a New Mexico Water Quality Control Commission (NM WQCC) Regulation 3103 ground water standard or a RCRA regulatory limit the Laboratory will coordinate disposal with the NMED. Since the drilling fluids produced from Workplan Well R-32 exceeded the NM WQCC Regulation 3103 ground water standard for manganese (Mn), your agency's concurrence was requested.

The Laboratory has containerized approximately 80,000 gallons of ground water produced during the development of Workplan Well R-32. It is expected that an additional 20,000 gallons of development water will be produced within the next week as well development is completed. Workplan Well R-32 is located along Pajarito Road southeast of Technical Area (TA)-18. In accordance with our proposal, all development water from Workplan Well R-32 will be land applied adjacent to the drill site. As required by the Workplan NOI, no ponding, pooling, or run-off of the discharged water will be permitted. Information regarding the quality of the development water is provided below.

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Mr. Young and Mr. Frischkorn  
RRES-WQH:02-372

- 2 -

October 8, 2002

### Water Quality Data

The enclosed Table 1.0 is a summary of water quality data (metals, general chemistry, perchlorate, nitrate, tritium, and high explosives) for the approximately 80,000 gallons of containerized development water from Workplan Well R-32. Attachment 1.0 contains copies of the analytical reports. All samples were filtered prior to analysis. Sample results were compliant with all NM WQCC Regulation 3103 ground water standards with the exception of manganese (Mn).

| Contaminant | Max. Result<br>(mg/L) | Min. Result<br>(mg/L) | WQCC ground water<br>standard (mg/L) |
|-------------|-----------------------|-----------------------|--------------------------------------|
| Mn          | 3.89                  | 0.74                  | 0.2                                  |

Cobalt exceeded the NM WQCC ground water standard of 0.05 mg/L in one of the three development water samples collected; however, the average cobalt concentration of 0.036 mg/L was less than the NM WQCC ground water standard. No perchlorate, tritium, or high explosives were detected in the Workplan Well R-32 development water at concentrations greater than the analytical laboratory's Method Detection Limits (MDLs). Nitrate/nitrite (as N) was detected at a maximum concentration of 0.43 mg/L.

Please call me at (505) 667-6969 or Roy Bohn of the Laboratory's Environmental Restoration Project (RRES-R) at (505) 665-5138 if additional information is required.

Sincerely,



Bob Beers  
Water Quality & Hydrology Group

BB/tml

Enclosures: a/s

Cy: J. Davis, NMED/SWQB, Santa Fe, NM, w/ enc.  
J. Vozella, DOE/OLASO, w/ enc., MS A316  
G. Turner, DOE/OLASO, w/ enc., MS A316  
M. Johansen, DOE/OLASO, w/ enc., MS A316  
J. Holt, ADO, w/o enc., MS A104  
B. Ramsey, RRES-DO, w/o enc., MS J591  
K. Hargis, RRES-DO, w/o enc., MS J591  
D. Stavert, RRES-EP, w/enc., MS J978  
S. Rae, RRES-WQH, w/enc., MS K497  
D. Rogers, RRES-WQH, w/o enc., MS K497  
M. Saladen, RRES-WQH, w/enc., MS K497  
R. Bohn, RRES-R, w/enc., MS M992  
D. McInroy, RRES-R, w/o enc., MS M992  
RRES-WQH File, w/enc., MS K497  
IM-5, w/enc., MS A150

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Table 1.0. Screening Results, R-32 Development Water. Filtered Samples.

| Analyte                | R-32<br>Results<br>GW32-02-47655<br>(mg/L) | R-32<br>Results<br>GW32-02-47999<br>(mg/L) | R-32<br>Results<br>GW32-02-49619<br>(mg/L) | R-32<br>Results<br>R-32 10-02-02<br>(mg/L) | NM WQCC<br>3103<br>Standards<br>(mg/L) |
|------------------------|--|--|--|--|--|
| Ag                     | <0.0002                                    | <0.0002                                    | <0.0002                                    |  | 0.05                                   |
| Al                     | 0.17                                       | 0.12                                       | 0.041                                      |  | 5.0                                    |
| As                     | 0.0031                                     | 0.0055                                     | 0.0017                                     |  | 0.1                                    |
| Ba                     | 0.11                                       | 0.17                                       | 0.068                                      |  | 1.0                                    |
| B                      | 0.04                                       | 0.03                                       | 0.18                                       |  | 0.75                                   |
| Cl                     | 26.1                                       | 46.0                                       | 10.6                                       | 7.71                                       | 250                                    |
| ClO <sub>4</sub>       | <0.005                                     | <0.005                                     | <0.002                                     |  |  |
| Co                     | 0.011                                      | 0.084                                      | 0.014                                      |  | 0.05                                   |
| Cd                     | <0.001                                     | <0.001                                     | <0.001                                     |  | 0.01                                   |
| Cr                     | 0.009                                      | 0.010                                      | 0.0024                                     |  | 0.05                                   |
| Cu                     | 0.019                                      | 0.015                                      | 0.0046                                     |  | 1.0                                    |
| F                      | 0.55                                       | 0.50                                       | 0.67                                       | 0.69                                       | 1.6                                    |
| Fe                     | 1.04                                       | 0.78                                       | 0.46                                       |  | 1.0                                    |
| <sup>3</sup> H (pCi/L) |  | <111.23                                    |  |  |  |
| HE                     |  |  | <0.01                                      |  |  |
| Hg (filtered)          | 0.00009                                    | 0.00007                                    | 0.00009                                    |  | 0.002 <sup>1</sup>                     |
| Mn                     | 1.77                                       | 3.89                                       | 0.91                                       | 0.74                                       | 0.2                                    |
| Mo                     | 0.0070                                     | 0.0033                                     | 0.0031                                     |  | 1.0                                    |
| NO <sub>3</sub>        | 0.13                                       | <0.2                                       | <0.2                                       | 0.43                                       | 10.0                                   |
| Ni                     | 0.077                                      | 0.11                                       | 0.020                                      |  | 0.2                                    |
| Pb                     | 0.0010                                     | 0.0007                                     | <0.0002                                    |  | 0.05                                   |
| Se                     | 0.0011                                     | 0.0017                                     | <0.001                                     |  | 0.05                                   |
| SO <sub>4</sub>        | 12.3                                       | 10.2                                       | 8.07                                       | 7.29                                       | 600                                    |
| U                      | <0.0002                                    | <0.0002                                    | 0.0003                                     |  | 5.0                                    |
| Zn                     | 0.012                                      | 0.024                                      | 0.005                                      |  | 10.0                                   |

<sup>1</sup>Total Hg

## **ATTACHMENT 1.0**

# **ANALYTICAL REPORTS**

## **SCREENING RESULTS**

### **HYDROGEOLOGIC WORKPLAN WELL R-32**

## **DEVELOPMENT WATER**

- **Tritium**
- **HE**
- **Metals**
- **General Inorganics**
- **Perchlorate**



1903 Central Ave. • Los Alamos, New Mexico 87544  
(505) 663-0363 • Fax (505) 663-0365

ARSNM Tracking Number: ARSNM-02-0112  
Client I.D.: GW32-02-47999  
Date Sampled: 09/27/02  
Time Sampled: 1340  
Type of Sample: liquid  
Contact Person: R. Evans

COC Number: 48402  
ARSNM Sample I.D.: ARSNM-02-0742  
Date Received: 09/27/02  
Time Received: 1435  
Date of Report: 10/03/02  
Charge Code: REPEATED

| Analysis Description | Analysis Result | Analysis Error<br>$\pm 2 \sigma$ % | Detection Limit | Analysis Units | Analysis Test Method | Analysis Date & Time | Analysis Technician |
|----------------------|-----------------|------------------------------------|-----------------|----------------|----------------------|----------------------|---------------------|
| Tritium              | BDL             | N/A                                | 111.23          | pCi/l          | EPA 906.0M           | 09/28/02<br>0758     | bz                  |
| Gross Alpha          | BDL             | N/A                                | 190.77          | pCi/l          | EPA 900M             | 10/03/02<br>1025     | bz                  |
| Gross Beta           | BDL             | N/A                                | 506.87          | pCi/l          | EPA 900M             | 10/03/02<br>1025     | bz                  |
| Gross Gamma          | 913.79          | 127.47                             | 283.54          | pCi/l          | EPA 901.1M           | 09/27/02<br>1942     | bz                  |

B. Zelenay  
Barbara Zelenay

Cost per sample:

Notes: American Radiation Services of New Mexico assumes no liability for the use or interpretation of any analytical results provided other than the cost of the performed analysis itself. Reproduction of this report in less than full requires the written consent of the client.

ER

| ER WATER SAMPLES |                                |          |       |      |         |       |
|------------------|--------------------------------|----------|-------|------|---------|-------|
| SAMPLE ID        | DESCRIPTION                    | DATE     | ER    | Temp | Ag      | Al    |
|                  |                                | MM/DD/YY | Req#  | °C   | ppm     | ppm   |
| GW32-02-49619    | R-32, 1320', (TIC/TOC) 10/2/02 | 09/30/02 | 1291S | 22.1 | <0.0002 | 0.041 |

ER

| SAMPLE ID     | Std.D.<br>+/- | Alk(Lab)<br>ppm CaCO3 | As Std.D.<br>ppm +/- | B Std.D.<br>ppm +/- | Ba Std.D.<br>ppm +/- | Be<br>ppm | Br<br>ppm |
|---------------|---------------|-----------------------|----------------------|---------------------|----------------------|-----------|-----------|
| GW32-02-49619 | 0.001         | 53.7                  | 0.0017 0.0001        | 0.18 0.01           | 0.068 0.001          | <0.001    | 0.19      |

ER

| SAMPLE ID     | C TIC<br>ppm | C TOC<br>ppm | Ca Std.D.<br>ppm +/- | Cd<br>ppm | Cl<br>ppm | ClO3<br>ppm | ClO4<br>ppm | Co Std.D.<br>ppm +/- |
|---------------|--------------|--------------|----------------------|-----------|-----------|-------------|-------------|----------------------|
| GW32-02-49619 | 18.6 (17.6)  | 9.32 (7.70)  | 17.6 0.1             | <0.001    | 10.6      | <0.02       | <0.002      | 0.014 0.001          |

ER

| SAMPLE ID     | CO3<br>ppm | Cond. (F)<br>µS/cm | Cr Std.D.<br>ppm +/- | Cs<br>ppm | Cu Std.D.<br>ppm +/- | F<br>ppm | Fe Std.D.<br>ppm +/- |
|---------------|------------|--------------------|----------------------|-----------|----------------------|----------|----------------------|
| GW32-02-49619 | 0          | 221                | 0.0024 0.0001        | <0.001    | 0.0046 0.0001        | 0.67     | 0.46 0.01            |

ER

| SAMPLE ID     | Hardness<br>CaCO <sub>3</sub> ppm | HCO <sub>3</sub><br>ppm | Hg<br>ppm | Std.D.<br>+/- | K<br>ppm | Std.D.<br>+/- | Li<br>ppm | Std.D.<br>+/- | Mg<br>ppm | Std.D.<br>+/- | M<br>ppm |
|---------------|-----------------------------------|-------------------------|-----------|---------------|----------|---------------|-----------|---------------|-----------|---------------|----------|
| GW32-02-49619 | 65.2                              | 65.5                    | 0.00009   | 0.00001       | 1.95     | 0.02          | 0.035     | 0.001         | 5.17      | 0.03          | 0.9      |

ER

| SAMPLE ID     | Std.D.<br>+/- | Mo<br>ppm | Std.D.<br>+/- | Na<br>ppm | Std.D.<br>+/- | Ni<br>ppm | Std.D.<br>+/- | NO2<br>ppm | NO3<br>ppm | Oxalate<br>ppm | Pb<br>ppm |
|---------------|---------------|-----------|---------------|-----------|---------------|-----------|---------------|------------|------------|----------------|-----------|
| GW32-02-49619 | 0.04          | 0.0031    | 0.0001        | 21.1      | 0.2           | 0.020     | 0.001         | <0.02      | <0.02      | <0.02          | <0.0002   |

ER

| SAMPLE ID     | pH<br>Field | pH<br>Lab | PO4<br>ppm | Rb<br>ppm | Std.D.<br>+/- | Sb<br>ppm | Se<br>ppm | Si<br>ppm | Std.D.<br>+/- | SiO2<br>ppm calc |
|---------------|-------------|-----------|------------|-----------|---------------|-----------|-----------|-----------|---------------|------------------|
| GW32-02-49619 | 6.82        | 6.67      | 7.39       | 0.005     | 0.001         | <0.001    | <0.001    | 33.5      | 0.6           | 71.7             |

ER

| SAMPLE ID     | SO4<br>ppm | Sn<br>ppm | Sr Std.D.<br>ppm +/- | Th<br>ppm | Ti<br>ppm | Tl<br>ppm | U Std.D.<br>ppm +/- | V std.D.<br>ppm +/- |
|---------------|------------|-----------|----------------------|-----------|-----------|-----------|---------------------|---------------------|
| GW32-02-49619 | 8.07       | <0.001    | 0.093 0.001          | <0.001    | <0.001    | <0.001    | 0.0003 0.0001       | 0.005 0.001         |

ER

| SAMPLE ID     | Zn Std.D.<br>ppm +/- | TDS<br>ppm | HMX<br>ppm | RDX<br>ppm | 1,3,5-TNB<br>ppm | 1,3-DNB<br>ppm | TNT<br>ppm |
|---------------|----------------------|------------|------------|------------|------------------|----------------|------------|
| GW32-02-49619 | 0.005 0.001          | 211.8      | <0.01      | <0.01      | <0.01            | <0.01          | <0.01      |

ER

| SAMPLE ID     | NB 2a-4,6-DNT<br>ppm | ppm   | 2,4-DNT<br>ppm | Acetate<br>ppm | Formate<br>ppm |
|---------------|----------------------|-------|----------------|----------------|----------------|
| GW32-02-49619 | <0.01                | <0.01 | <0.01          | ++             | ++             |